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EXPERIMENTAL EVALUATION OF FLOW MEASUREMENT TECHNIQUES IN THE OHRD TRITIUM LABORATORY

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ABSTRACT

Four flow measurement techniques, namely, conventional hot wire anemometer (HWA), Laser Doppler anemometer (LDA), smoke, and tracer gas were evaluated experimentally in Ontario Hydro Research Division's Tritium Laboratory. Both LDA and HWA were found to be adequate for measuring high flows at exhaust and inlet grilles but only LDA may provide the accuracy necessary for measuring very low flows (<< 1 m/s). Smoke tests were found to be very useful to study the air movement qualitatively whereas the tracer gas technique could determine the effective purge rate in an area quantitatively.

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Table of Contents

		Page
1.0	INTRODUCTION	1
2.0	EXPERIMENTAL PROGRAM OF THE TRACER GAS STUDY	1
3.0	RESULTS AND DISCUSSIONS OF THE TRACER GAS STUDY	3
4.0	APPLICATIONS OF THE VARIOUS FLOW MEASUREMENT TECHNIQUES IN ONTARIO HYDRO'S NUCLEAR FACILITIES	8
REFERENCES		12

List of Figures

	Page
Figure 1 - Schematic Diagram of the Gas Release and Analysis System	2
Figure 2 - Schematic Diagram of the OHRD Tritium Laboratory	6
Figure 3 - SF_6 Concentration as a Function of Time	10

List of Tables

Table 1 - Condition of the Ventilation System in the Tritium Laboratory for the Two Tracer Gas Tests	4
Table 2 - Summary of the Tracer Gas Concentration (in ppm) at Various Locations in the Tritium Laboratory during the two tests.	7
Table 3 - Concentration of SF_6 after the Termination of Gas Release (at 11.7 m from North Wall, 10.8 m from West Wall and 1.5 m above ground)	9

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EXPERIMENTAL EVALUATION OF FLOW MEASUREMENT
TECHNIQUES IN THE OHRD TRITIUM LABORATORY

1.0 INTRODUCTION

Ontario Hydro is interested in a simple, reliable, non-intrusive, and reasonably accurate technique for measuring ventilation flow rates at exhaust and inlet grilles and air movements in nuclear generating stations. The technique should be usable by a technician with one assistant. Assuming grille accessibility, it should be possible to measure flows at about 10 grilles per hour./1/

In this phase of the study, four techniques were evaluated experimentally, namely, conventional hot wire anemometer (HWA), Laser Doppler anemometer (LDA), smoke, and tracer gas (TG). The study was carried out at Ontario Hydro Research Division's Tritium Laboratory. King's Engineering carried out the HWA and LDA tests and a smoke test which was video-taped. LDA equipment suitable for use in Ontario Hydro's nuclear facilities is also specified by King's Engineering together with a computer program for data logging and analysis of HWA and LDA measurements. Their report is attached to this report as the Appendix. Two tracer gas tests were carried out by the Chemical Research Department to study the air movement in the OHRD Tritium Laboratory. The experimental program and results of the tracer gas study are presented, and the results of the King's Engineering's study and applications of the various techniques in Ontario Hydro's nuclear facilities are discussed briefly in this report.

2.0 EXPERIMENTAL PROGRAM OF THE TRACER GAS STUDY

A schematic diagram of the equipment used for gas release and analysis is shown in Figure 1. The tracer gas used in this study is SF_6. Pure SF_6 was released from a compressed gas cylinder through a 0.6 mm copper tubing and the flow rate was controlled by a mass flow controller. The MIRAN 1A infra-red analyzer was used to determine the SF_6 concentrations in air samples taken at various points in the Tritium Laboratory. The signal output from the analyser was recorded continuously by a chart recorder. A

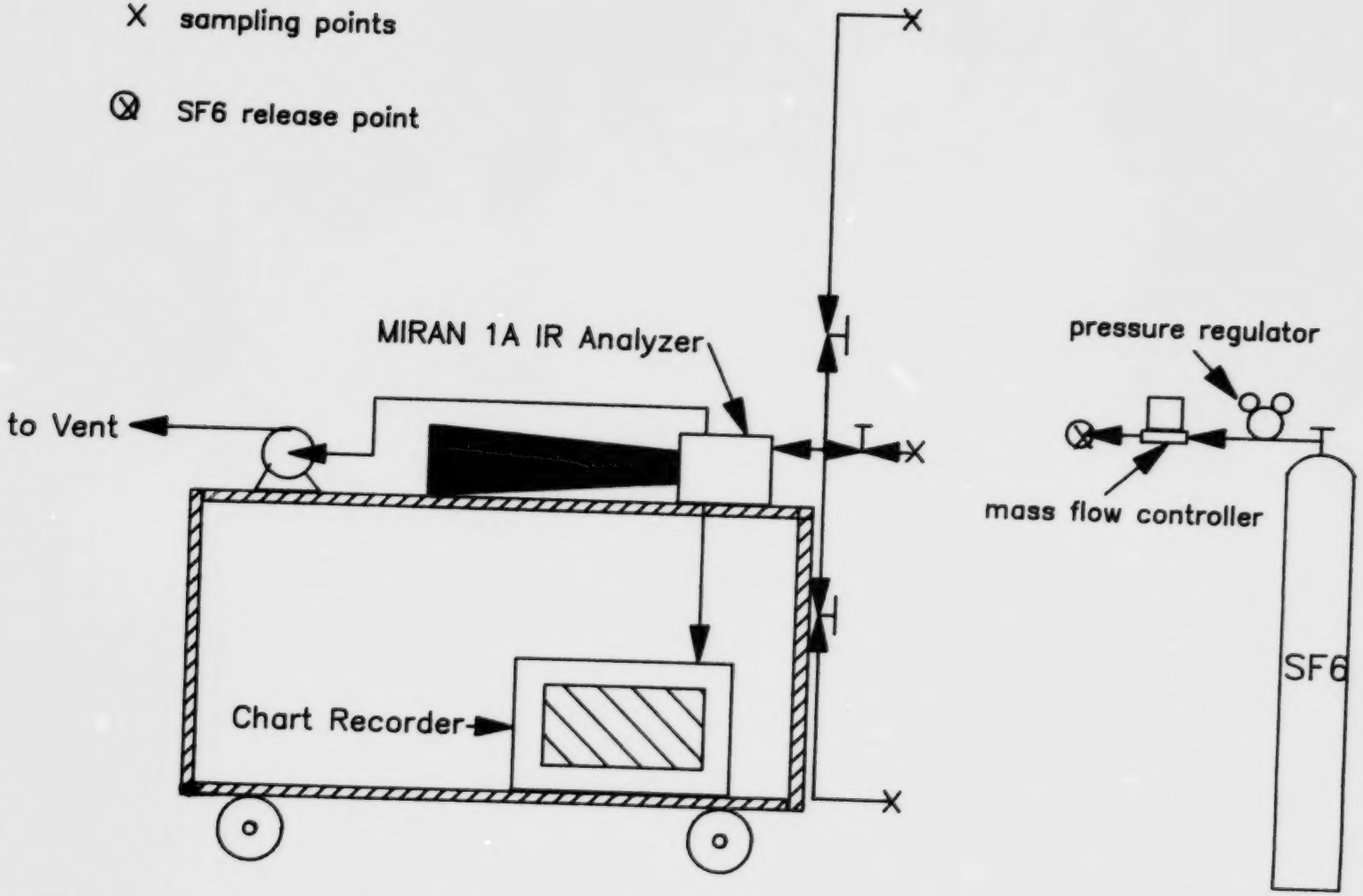


Figure 1. Schematic Diagram of the Gas Release and Analysis System

small air pump was used to draw air through the sample system and the gas analyser. The outlet of the pump was connected to one of the ceiling ventilators so that the gas sample was vented out of the Tritium Laboratory. The sampling system consisted of 1.25 mm copper pipes with three sampling points, one at 0.3 m, one at 1.5 m and one at 10 m above the floor. The sampling point was selected by opening and closing the manual valves leading to the sampling points. The entire sampling and gas analysis system was assembled on a trolley and could be moved to any location in the Laboratory to determine the gas concentration at that point.

Two experiments were carried out to study the air movement in the Tritium Laboratory. The condition of the ventilation system was identical for both tests and is summarized in Table 1. For each experiment, SF_6 was released at a constant rate of 30 mL/min from a fixed location. The concentration of the SF_6 was monitored at a selected location for about two hours until the concentration at that location became relatively constant. The concentrations of the tracer gas at various locations in the Tritium Laboratory were then determined by sampling and analyzing the gas at each location. In the second experiment, after a complete survey of the gas concentration in the Tritium Laboratory, the release of SF_6 was terminated but the analysis of the gas sample at various locations in the laboratory was continued for another two to three hours until the concentration of the tracer gas approached the background level.

3.0 RESULTS AND DISCUSSIONS OF THE TRACER GAS STUDY

Assuming that the air in the Tritium Laboratory is well-mixed with a release of tracer gas at a constant rate and a constant ventilation flow, then it can be shown that at steady state:

$$C_s = R / Q \qquad (1)$$

where C_s is the steady state concentration of SF_6;
R is the release rate of the tracer gas; and
Q is the ventilation flow rate.

If the release of the tracer gas is terminated, the concentration of the tracer gas in the Tritium Laboratory will decay according to the following equation (again assuming that the air in the laboratory is well-mixed):

$$\text{Ln}\,(C) - \text{Ln}\,(C_i) = -(Q/V)t \qquad (2)$$

where C is the concentration of the tracer gas at time t;
C_i is the initial concentration of the tracer gas;
Q is the ventilation flow rate;
V is the volume of the Laboratory; and
t is the time.

TABLE 1

CONDITION OF THE VENTILATION SYSTEM IN THE TRITIUM LABORATORY FOR THE TWO TRACER GAS TESTS

Device #	Type	Position
1	V	O
2	V	C
3	V	C
4	V	C
5	V	C
6	V	O
7	V	C
8	V	C
9	V	C
10	F	O
11	F	O
12	V	C
13	F	O
14	F	O
15	F	O
16	F	O

V = Ventilator
F = Fume Hood
O = Open
C = Closed

However, if the air in the Laboratory is not well mixed and there are areas in which the ventilation flow is not effective in purging the air then Q in these equations is an indication of the effective purge rate of any gaseous component due to the ventilation flow in the Laboratory. This effective purge rate may vary depending on the release point of the tracer gas and also vary as a function of time and location in equation (2).

In the first experiment, SF_6 was released at a rate of 30 mL/min near the Tritium Supply and Delivery System glovebox and 1.5 m above the floor (see Figure 2). The concentration of SF_6 at 8.1 m from the north wall and 7.2 m from the west wall was determined continuously for two hours after the start of the release. The concentration started to increase in less than 2 minutes from background which is less than 100 ppb to over 1.5 ppm in 8 minutes and fluctuated between 1.2 to 2.5 ppm in the next 1.5 hours. The concentrations at the various points in the laboratory were determined and all the data are summarized in Table 2. The concentration contours in the laboratory are shown in the King's Engineering's report attached as the appendix. Most of the concentrations are in the range of 1 to 3.5 ppm range. Concentrations significantly above 3.5 ppm were found at only three sampling points. The concentrations at 0.6 m and 4.2 m from the west wall were slightly lower, generally less than 2 ppm and became 2 ppm or higher towards the east wall of the Laboratory. The concentrations showed no obvious trends and were in fact similar with respect to the vertical direction. The overall average concentration of all the measurements taken was 2.1 ppm. Assuming that this is the steady state average concentration in the Tritium Laboratory, then the effective purge rate in the Laboratory is estimated to be .238 m^3/s by using equation (1). This indicates that the effective purge rate for the tracer gas released near the Tritium Supply and Delivery System glovebox is much lower than the actual ventilation flow which was designed to be 1.42 m^3/s. During this first tracer gas test, it was found that the wall heaters were not operating, resulting in poor mixing, hence a much lower effective purge rate than the actual ventilation flow. This is consistent with the results of the smoke tests carried out by King's Engineering which also showed that the wall heaters had a significant effect on the air movement in the Tritium Laboratory.

In the second experiment, SF_6 was released from near the entrance door to the Tritium Laboratory (see Figure 2) at a rate of 30 mL/min. The concentration of SF_6 was monitored at 8.1 m from the north wall, 7.2 m from the west wall and 1.5 m above the floor. The SF_6 concentration started to increase above background in about 3 minutes and reached 0.50 ppm in 40 minutes and was 0.54 ppm after two hours. The SF_6 concentration at various locations in the Laboratory was determined and the results are summarized in Table 2. The average of all the measurements taken was 0.6 ppm. Again, assuming that this is the steady state average concentration in the Laboratory with a SF_6 release rate of 30 mL/min, the effective purge rate is estimated to be 1.07 m^3/s. In this experiment, the SF_6 concentration at 11.7 m from the north wall, 10.8 m from the west wall and 1.5 m above ground was monitored after the SF_6 release was terminated. Results are

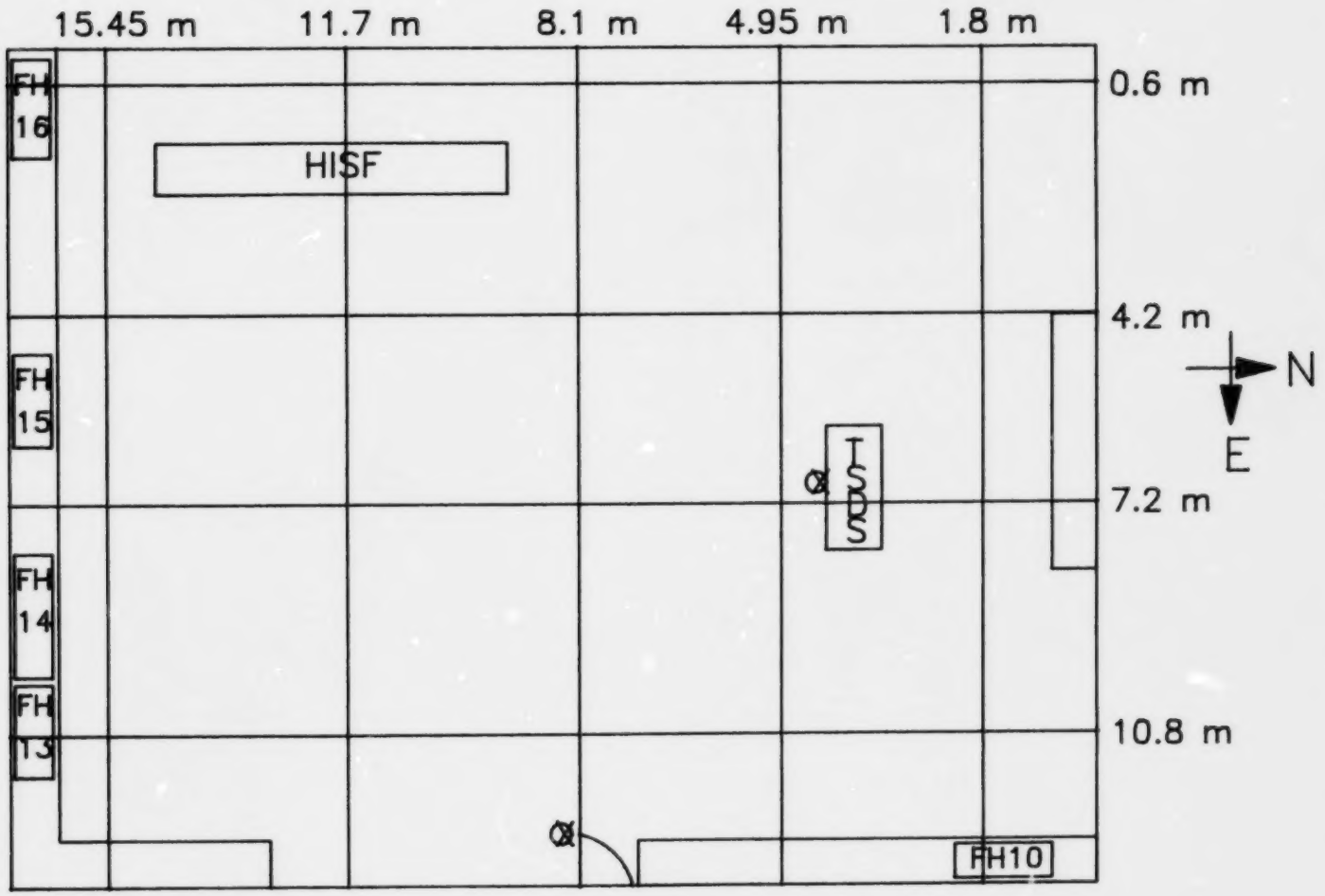


Figure 2. Schematic Diagram of the OHRD Tritium Laboratory

TABLE 2

SUMMARY OF THE TRACER GAS CONCENTRATION (IN PPM) AT
VARIOUS LOCATIONS IN THE TRITIUM LABORATORY DURING THE TWO TESTS

Height	0.3 m				1.5 m				3 m			
Distance from West Wall (m) / Distance from North Wall (m)	0.6	4.2	7.2	10.8	0.6	4.2	7.2	10.8	0.6	4.2	7.2	10.8
Test #1	(release near the TSDS glovebox, wall heater not operating)											
1.8	1.45	1.45	1.43	1.27	1.40	1.53	2.07	1.42	1.15	1.73	2.40	1.97
4.95	1.45	1.26	2.60	1.66	1.43	1.92	3.52	1.86	1.80	1.51	5.20	1.97
8.1	1.23	1.70	1.51	9.60	1.25	1.66	1.97	5.72	1.33	1.66	2.13	2.60
11.7	1.12	1.55	1.62	3.38	1.12	1.70	1.62	3.52	1.20	1.70	1.66	2.22
15.45	1.10	1.39	2.60	3.33	1.20	1.66	2.03	3.23	1.15	1.66	1.97	2.22
Test #2	(release near the entrance door, room heater operating)											
1.8	0.40	0.33	0.53	0.54	0.33	0.36	0.43	0.44	0.27	0.50	0.42	0.41
4.95	0.42	0.42	0.43	0.39	0.44	0.44	0.53	0.41	0.42	0.60	0.57	0.53
8.1	0.53	0.40	0.40	0.74	0.54	0.42	0.54	0.72	0.52	0.53	0.74	2.60
11.7	0.55	0.54	0.39	0.59	0.56	0.60	0.60	2.25	0.58	0.75	0.75	1.85
15.45	0.63	0.26	0.33	0.57	0.61	0.28	0.52	1.00	0.69	0.47	0.53	0.95

summarized in Table 3 and the decay of the SF_6 concentration at that location was plotted as a function of time on a semi-Log scale in Figure 3. The initial rate of decay of the SF_6 concentration was relatively high and decreased gradually as the time increased. Using equation (2) and taking the initial slope of the curve, the initial effective purge rate at this location was estimated to be 1.32 m^3/s. The slope decreased gradually and at 20 minutes after the termination of the release, the effective purge rate was reduced to 0.72 m^3/s at this location. These purge rates were significantly higher than that in the first tracer gas test but still lower than the designed ventilation flow of 1.42 m^3/s for the Tritium Laboratory. The operation of the ventilation system was identical in the two tests except that the wall heaters were operating in the second test but not in the first test. This result showed that the wall heater has a dominant effect on the mixing of the air in the Tritium Laboratory.

4.0 APPLICATIONS OF THE VARIOUS FLOW MEASUREMENT TECHNIQUES IN ONTARIO HYDRO'S NUCLEAR FACILITIES

There are several areas that flow measurements may be required in our nuclear facilities. These areas will be discussed separately in the following:

1. Ventilation flows at exhaust and inlet grilles

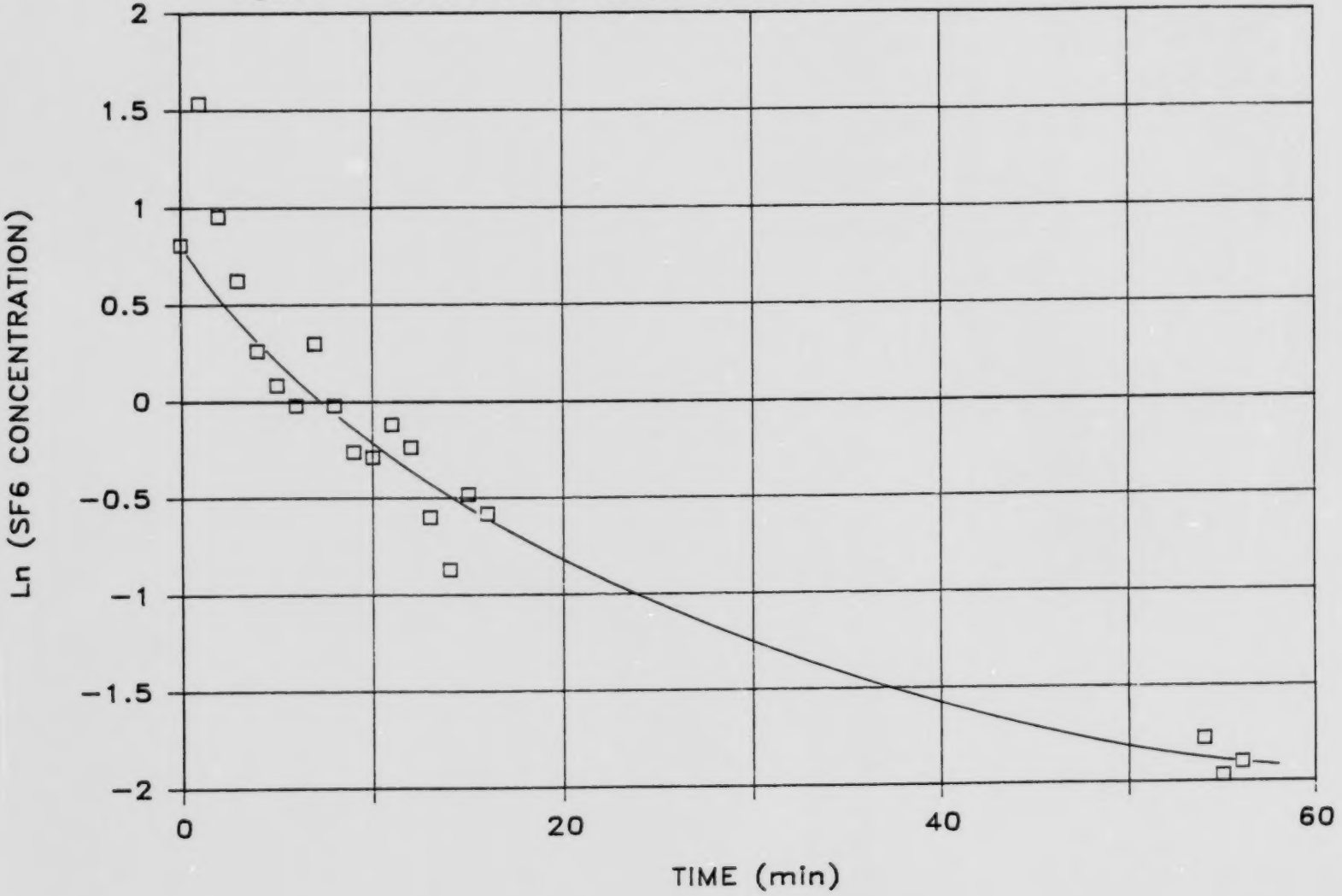
For this application, it is most likely that the HWA and LDA would be appropriate for the measurements. The advantages and disadvantages of both techniques are discussed in detail in the King's Engineering's report. The LDA system is relatively complicated and expensive. However, it does not require calibration and is capable of measuring very low velocities (<< 1 m/s) which may be important in some of the applications whereas the accuracy of the HWA decreases as the velocity falls below 1 m/s and frequent calibration of the probe may be required for the lower velocities. Both techniques require a probe supporting unit and a data logging and analysis system. The data logging and analysis system may be relatively simple by using the computer program provided by King's Engineering and a personal computer. The design of the probe support unit will depend on the level of automation required. It can vary from a simple mechanical tool capable of two-dimensional traverses to a fully automated robatic arm with computer control. In most cases, a simple two-dimensional traverse mechanical device that can be attached to the ventilation duct work with sensors to identify the location of the probe and input to the personal computer may be sufficient. It is unlikely that either of the techniques can measure flows at ten grilles per hour following the recommended number of measurements to define the flow rate at a grille or duct/2/, but one to two grilles per hour is possible. It may be possible to minimize the number of measurements required to characterize the flow for each grille so that more grilles can be studied per hour. However, reducing the number of measurements will reduce the accuracy of the estimated flow rate for the grille and the minimum number of measurement with an acceptable error bound of the estimated flow rate must be determined.

TABLE 3

CONCENTRATION OF SF_6 AFTER THE TERMINATION OF GAS RELEASE
(AT 11.7 M FROM NORTH WALL, 10.8 M FROM WEST WALL AND 1.5 M ABOVE GROUND

Time (min)	SF_6 Concentration (ppm)
0	2.25
1	4.65
2	2.60
3	1.87
4	1.30
5	1.09
6	0.98
7	1.35
8	0.98
9	0.77
10	0.75
11	0.89
12	0.79
13	0.55
14	0.42
15	0.62
16	0.56
54	0.17
55	0.14
56	0.15

Figure 3 - SF6 CONCENTRATION AS A FUNCTION OF TIME



2. Air movement or ventilation in an area of concern

In many cases, the purpose of determining flows at exhaust and inlet grilles is to study the effectiveness of the ventilation system to provide heating or cooling and/or to remove airborne or gaseous contaminants from a particular work area. In addition to determining the flow at ventilation grilles, it may be necessary to study the overall air movement in the area to identify the most suitable way of properly ventilate the area. For this application, it is unlikely that the HWA or LDA be suitable. Smoke tests as demonstrated by the King's Engineering's study can show general flow patterns in the area very well. In addition, it can also show the instantaneous effect of changes in the area such as opening or closing of doors, turning on or off an ventilator, or equipment or personnel movement in the area. Tracer gas technique was also applied to study the air movement in the Laboratory as discussed earlier in this report. The main advantage of the tracer gas technique is that the effective purge rate in the Tritium Laboratory or in any other nuclear facilities as a result of the ventilation flow can be quantified. Hence, in case of a tritium leak at the locations studied, the level of contamination in the nuclear facility can be quantified as a function of time. Another advantage of this technique is that since SF_6 is non-toxic, odorless, chemically stable and its background is extremely low, it can be used during the day without interfering the operation of the nuclear facility. This technique was used at Bruce A Nuclear Generating Station to study ventilation flow and other applications of the technique were also identified/3/. Hence, both the smoke tests and tracer gas tests may be useful depending on the information required for a particular study.

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Experimental Evaluation of Flow Measurement Techniques

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TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	iii
ACKNOWLEDGEMENTS	iv
1. INTRODUCTION	
1.1 Hot Wire Anemometry and Pitot Tubes	1
1.2 Laser Doppler Anemometry	2
1.3 LDA Theory	2
1.4 Different LDA Techniques	4
2. EXPERIMENTAL MEASUREMENTS	
2.1 Measurements Made by Kings Engineering	6
2.1.1 Fume Hoods and Ventilators	6
2.1.2 Room Aerodynamics	8
2.2 Measurements Made by Ontario Hydro Research	8
3. EXPERIMENTAL RESULTS	
3.1 Ventilator Flows	9
3.2 Fume Hood Flows	9
3.3 Room Aerodynamics	10
3.4 Gas Concentration Measurements	10
4. RECOMMENDED TECHNIQUES AND EQUIPMENT	
4.1 Recommended Method for Flow Rate Determination	12
4.2 Recommended Method for Room Aerodynamics	12
4.3 LDA System Recommendation	13
4.3.1 Fiber Optic Probe	13
4.3.2 LDA Electronics	14

4.3.3 Manpower and Procedures 15

APPENDIX A - EQUIPMENT USED A.1

APPENDIX B - FIGURES CITED B.1

APPENDIX C - TABULATED DATA C.1

APPENDIX D - MANUAL FOR PC PROGRAM FOR FLOW RATE DETERMINATION D.1

APPENDIX E - MANUFACTURERS' DATA E.1

EXECUTIVE SUMMARY

This report describes a series of tests which were carried out to experimentally evaluate the applicability of various techniques for measuring air flow and air movement. The ultimate application sites for the chosen technique are Ontario Hydro's Nuclear Generating Stations and the Darlington Tritium Removal Facility. Selection of the technique to be used will be made by Ontario Hydro.

In order to evaluate the most appropriate techniques, a series of tests was carried out in the Ontario Hydro Research Division's Tritium Laboratory. The tests involved measurements made using Laser Doppler Anemometry (LDA), Hot Wire Anemometry (HWA), smoke flow visualization, and a tracer gas. The last-mentioned set of measurements was made by Ontario Hydro personnel.

The results of the test program suggest that a suitably-designed LDA system is well suited to meeting the requirements of the application areas. The report contains quantitative data on the velocity measurements which were made, and a VHS video cassette accompanies the report which illustrates the nature of the flow field in the Tritium Laboratory. Finally, the report contains a detailed specification of the equipment which would be required to carry out such measurements in the application areas.

ACKNOWLEDGEMENTS

The study reported here was carried out for King's Engineering Associates Ltd., by Colette E. Taylor and John R. Nickerson. The time commitment and dedication of these two individuals is gratefully acknowledgemented.

The co-operation offered by Dr. C.H. Cheh and other Ontario Hydro personnel is also acknowledged. Without their assistance in accessing the Tritium Laboratory and setting up measurement systems, the project could not have been completed.

CHAPTER 1

INTRODUCTION

1.1. Hot Wire Anemometry and Pitot Tubes

Fluid (gas or liquid) velocity may be measured by a number of means such as pitot probes and heated wires introduced into the flow. While these techniques have sufficed over the years, there are times that these devices disturb the flow unacceptably by their presence or indeed the environment may be too hostile for these measuring instruments to function or exist. Further these techniques have limited accuracy when used in flows where the turbulence (degree of fluctuating velocity over a mean level) is high or where the flows reverse in direction over small distances and at very low velocities. In the case of pitot probes at low velocities, extremely sensitive pressure transducers or micromanometers must be employed to make velocity measurements. Also the probe is somewhat insensitive to directional changes in the flow velocity. A Hot Wire Anemometer (HWA) uses a heated wire as a sensor and depends on convective cooling to generate a voltage proportional to velocity. A pitot probe generates a pressure which varies as the square of the speed of the flow, while a HWA generates a bridge voltage which varies as the fourth power of the velocity. The HWA must be calibrated especially at lower velocities (less than 1 m/sec.) and any dirt or contaminates that accumulate on the velocity sensor (a small diameter tungsten filament) will change the calibration. The HWA like the pitot probe may best be described as a speed sensor since they are insensitive to flow direction. Thus using these devices for making flow rate measurement is tenuous at best since volume flow rate is the area integral of the velocity normal to the control surface. Also, both devices must be calibrated against a standard for low velocity measurement and only two standards are commonly used: LDA and a mechanical carriage assembly such as found on towing channels facilities.

1.2. Laser Doppler Anemometry

Laser Doppler Anemometry (LDA) has many specific advantages:

i) non-intrusive or non-contacting velocity measurement

ii) provides high spatial resolution

iii) measures instantaneous velocity

iv) measures the component of velocity normal to the beam crossing

v) requires no calibration

vi) measured frequency is linearly related to velocity

vii) flow direction may be determined

LDA also has several disadvantages which must be weighed against its advantages:

i) expense. Single channel systems cost about 40k dollars and two channel or two component systems run up to 100k dollars.

ii) must have optical access to area of interest i.e. you must be able to see the measurement area.

iii) indirect method of velocity measurement.

iv) output signal is not continuous which makes spectral analysis difficult.

1.3. LDA Theory

The mechanism behind LDA may be described by two different models: a) the fringe model and b) the optical heterodyne. Since the principles of interferometry are commonly known, the former model will be used for describing LDA operation. Referring to figure 1.1 we see a schematic of a single component forward-scatter LDA system. The beam from a laser is split into two equal-intensity beams via the beam splitter shown. These two beams are focused by a lens and the volume at the intersection point (called the control volume) is the region over which the velocity measurement is made. A photodetector on the other side of the beam intersection senses the light input. Light may be considered as a propagating Electro-Magnetic wave. As such we would expect the waves from the two intersecting beams to constructively and destructively interfere. This produces a fringe pattern as

illustrated in figure 2.1. A particle in the flow which travels across the fringe pattern scatters more or less light depending on where it is relative to the fringes. This scattered-light signal is sensed by the photodetector as shown in figure 1.1. Note that since the beams are focused by a lens the control volume or region where the fringes appear can be made very small, ensuring good spatial resolution. Further, the fringes produced are normal to the beam intersection. The velocity sensed is then the component of velocity normal to the fringe pattern. One may note, however, that some sort of light scattering particle must be in the flow in order to generate a signal. In a real sense LDA only measures the velocity of the scattering particle and the accuracy of the technique depends on the particle following the fluid flow accurately. Fortunately this is the case provided that the particles are small enough. In tap water there are more than enough scattering particles, called seeding particles or seed, present. In air and most gas flows, however, additional particles, preferably in the 2-10μm range, must be added. In crossing the fringe pattern the signal corresponding to the light scattered by these particles is shown in figure 2.2. Note that the pattern, called a "Doppler Burst" has both low and high frequency components. The low frequency component is called a pedestal and is associated with the intensity variation within the laser beams. This is normally filtered off leaving the high frequency signal shown in figure 2.3. This signal is due solely to the particle crossing the fringes. The frequency of this signal is determined usually by counting the number of times the signal crosses the zero line in a given time interval. From physical considerations the fringe spacing, d_f, may be determined to be:

$$d_f = \frac{\lambda \sin\phi}{2} \tag{1}$$

The relationship between the Doppler or burst frequency f_d and the beam crossing angle ϕ, wavelength λ and the flow velocity U is:

$$f_d = \frac{U\ 2 \sin\phi}{\lambda} \tag{2}$$

Thus with the frequency f_d in hand, from monitoring the photodetector, the velocity may easily be determined. Note that the velocity frequency relationship is linear and all the constants are known since the beam crossing angle is set by the focal length of the lens and the wavelength of light is known for the laser used.

It is obvious from figure 2.1 that we have no way of knowing which direction the particles are crossing the fringe pattern, short of knowing the flow direction. This may not always be known and hence an apparent directional ambiguity exists. This may be overcome by inserting a device known as a Bragg cell in one of the lasers beams before the lens in figure 1.1. This imparts a frequency shift (of the order of 40 MHz.) to the beam passing through it. This causes the fringe pattern in figure 2.1 to rapidly traverse the control volume. The Doppler burst frequency is superimposed on this frequency when a particle traverses the control volume. If the particle is flowing in the direction of the fringes the Doppler frequency subtracts from the shift frequency and it adds to the shift frequency in the case of particles flowing in the opposite direction. Thus flow direction may be determined and the calibration of the device stays the same except for subtracting the shift frequency.

Up to now we have restricted ourselves to a single component system; that is we are measuring only one component of velocity. We could add a second set of laser beams (of different wavelength than the first) normal to the first set of beams and by focusing a second control volume to be coincident with the first two components of velocity could be measured. These systems are inherently expensive, not only from the extra optical components required, but also from the need for a multicolour laser.

1.4. Different LDA Techniques

The systems discussed thus far have been forward scatter LDA devices. In some cases optical access may be limited to only one side of an experiment. In cases such as this a back-scatter unit may be added to place the photodetector at the back of the optics unit and a mirror reflects back-scattered light received from the focusing lens into the detector. This change adds cost to the device and some signal degradation inevitably occurs.

Over the last four years considerable advances have been made in integrating the optical components of a LDA system into a small probe. Since the laser is usually the bulkiest item in a system it is remotely mounted and the light is piped to the LDA system via a fiber optic cable. Since the probe is usually designed to operate in the backscatter mode, the photomultiplier may also be remotely mounted and connected to the probe with a fiber optic cable. These systems offer the user a

compact unit that can be easily traversed, or even hand held. Further, these units are sealed and usually do not require any optical alignment except for aligning the transmitting fiber with the laser.

One of the prime difficulties with Laser Doppler Anemometry is that a signal is generated only when a scattering particle enters the control volume. This, of course, does not occur continuously or at regular intervals. This makes spectral analysis of the signal particularly difficult. Another problem which arises is that faster-moving particles traverse the control volume more often than slower-moving particles. This leads to a phenomena called velocity biasing since it can upset averaging results. For low velocity measurement, though, velocity averaging is easily obtained by taking an arithmetic mean.

Despite these disadvantages LDA continues to enjoy an ever increasing following of researchers who use it to make measurements which cannot be made any other way. For instance, velocity measurements are made in combustors of jet engines and combustion chambers of car engines. LDA can be used to measure surface velocities of red hot steel slabs or of molten glass. Even blood flows have been monitored with LDA.

CHAPTER 2

EXPERIMENTAL MEASUREMENTS

2.1. Measurements Made by Kings Engineering

2.1.1. Fume Hoods and Ventilators

The equipment used is listed in detail in appendix A. Essentially a single-component forward-scatter LDA system with a 15mW HeNe Laser was used. A custom-made seeder using silicon oil was used for seeding the flow. The LDA system was mounted on an aluminum-framed table which had a vertically-traversable top. This unit, in turn, was mounted on extender legs to elevate the system to approximately 4cm from the opening of the ventilator under study. A 37-point traverse grid was set up to give a 30cm by 30cm grid with 6cm spacing. (A central point was included to give 37 points.) These grids where marked on two sheets of quad paper and the carriage consisting of the LDA system, table and extender legs was positioned by pointers over the two patterns to ensure spatial uniqueness. Velocity measurements where made with the LDA system and the seeding flow was adjusted to give acceptable data rates. It should be noted that one has several options in terms of seeding from the seeding particle size, types of seeding medium, and location of the injection point. One can inject this seeding medium far from the measurement volume or fairly close to the beam intersection, as long as the seeding flow does not impart any momentum to the base flow. In this case the seeding, 2 to 10 μm spheres of silicon oil, was injected within 30cm of the control volume. However, it was pointed away from the velocity vector so that the seeding flow was slightly diverted by the main flow. In the case of the relatively high velocities in the ventilator openings this would offer no impediment to the flow. The option of mounting the seeder 1m away was considered but this was unnecessary. Since the LDA table and extender legs were an open framework they offered no resistance to the ventilator flow.

Ventilator #9 was the first ventilator examined, first with LDA, then a HWA traverse was conducted at this site. The HWA probe and sensor assembly were attached to the transmitting optics

barrel and the whole carriage was once again traversed through the grid points previously established. The calibration of the HWA sensor was performed at TRG/UTME[1] over a velocity range of 1 to 10m/sec.. For lower velocities it was calibrated against the LDA system. The equipment used for the HWA system is listed in Appendix A. The first ventilator of interest was #9 and the established condition of flow is given in table 1 in Appendix C. The second ventilator to have its flow rate measured was #4, but the total room flow conditions were changed. Table 1 in Appendix C gives the device numbers, identification and the flow damper position for the two different flow conditions.

After the LDA and HWA traverses were completed the LDA system and table were removed from the extender legs and the LDA system was mounted on the edge of the table. This was done to place the system close to the counter tops for the fume hood flow survey. The seeding input was placed 15cm below and normal to the beam intersection. The air flow rate through the seeder was adjusted with a bypass valve to provide the minimum data rate acceptable and the force of the seeding flow was imperceptible to the touch. Further, the main flow was blocked off and the seeding flow was rotated through the beam intersection and it was found to be impossible to induce a measurable flow at the seeding flow rates used. Further, with the seeding flow normal to the velocity vector (inflow) being measured, even if the seeding imparted some momentum to the flow it would not affect the LDA measurement of the main flow. The system was realigned and measurements were made first at fume hood #15 which is operated with the glass pane closed and air flows into the fume hood through three portals in the pane. For each portal a 5 by 5 grid was set up. After the LDA survey the HWA system was used to measure flow velocities and it was traversed over the same grid.

Similar traverses of both the LDA and HWA systems were also conducted at fume hood numbers 14 and 10. Here, a six by six rectangular grid was used.

2.1.2. Room Aerodynamics

Initially it was proposed to make an LDA traverse of the room with a very course grid at three different elevations. Doing this segment by LDA was abandoned since it would require flow

[1] Turbulence Research Group, University of Toronto, Mechanical Engineering

stationarity beyond what could reasonably be expected in the Tritium Laboratory. Further, unless a fine measurement grid was used, it would be difficult to interpret the results in a meaningful way. As an alternate it was proposed to use a smoke generator and video camera system to study the room air movement. The advantages of the method were that the smoke could be injected anywhere in the room and in and around ventilators and fume hoods to observe corner flows and unusual bypassing effects in fume hoods. The camera used had a stop watch function built in and this was synchronized by the operator to the smoke release and thus by watching the smoke travel through the room and observing the times, quantitative results could be determined. Smoke was released underneath the "TSDS" facility. This was done several times and after a few observations and some video work the entire sequence was repeated to gain the optimum effect through different camera positions. Smoke was also released around the ventilators and fume hoods to give a visual feel for the velocities encountered near these devices. Smoke was also injected in two of the corners of the room to examine local effects of room air movement. The entire result was recorded and edited on the video system and a voice track was added later. The VHS video cassette is included together with this report.

2.2. Measurements Made by Ontario Hydro Research

During the fume hood studies Ontario Research employees carried out a gas (SF_6) sampling survey. SF_6 was injected at a low rate into the room for two hours prior to the sampling measurements. The gas was sampled actively by a suction pump at three elevations and over a five by five grid for the entire room. The data from this survey is included in this report and commented on in the next section.

CHAPTER 3

EXPERIMENTAL RESULTS

3.1. Ventilator Flows

The flow data taken using the HWA and LDA systems is listed in tables 2,3 and 4 of Appendix C. The data were reduced by a data reduction-program (included as part of this report) which is given in Appendix D, together with a manual for describing its use. These data were contour plotted and integrated to give average velocity and flow rates which is listed in the tables. The contour plots are shown as figures 3,4 and 5 in Appendix B. The scale on the contour plot is the flow rate in cubic meters per second. The dark outline in the contour plots is the outline of the opening of the ventilator. The total flow rate for the device is given in the corresponding table. It can be noted that the iso-flow contours indicate a relatively flat velocity profile. These contours are plotted from the LDA data because of its greater accuracy. This is evidenced by the fact that the average velocities from the HWA were not consistently greater or less than the LDA values from the same traverse. There was a low frequency oscillation in the flow rate with a period of about ten seconds. However, even after averaging this out there is still a significant difference in the LDA versus HWA data for the ventilator series. Normally it would be expected that the HWA would read consistently higher than the LDA because of it being a speed sensor. It was apparent that while this was a factor, calibration drifts also are affecting the HWA performance. Ventilator number 4 was examined under two different flow conditions. The second condition produced markedly higher flow rates as evidenced by comparing figures 4 and 5 and the results in tables 3 and 4.

3.2. Fume Hood Flows

The fume hood results for the three portals of fume hood 15 are given tables 5,6 and 7, and the contour results are given in figures 6,7 and 8 for portals i), ii) and iii) respectively. Here it may be seen that the HWA system consistently reads much lower than the LDA result. In the range of velocities

encountered here (approximately 0.3 m/sec.) the HWA is not capable of producing accurate and consistent results even though it was calibrated against the LDA system. This is no doubt due to natural convective currents being set up from the heated sensor surface. Unless the flow velocity is high enough to sweep away these currents, inaccurate and irreproducable results will be generated. The contours generated from the LDA data once again demonstrate a flat velocity profile (with the dark lines indicating the portal boundary). The data for fume hoods 14 and 10 have been tabulated in tables 8 and 9. In order to give a better feel for the iso-flow contours they were plotted twice, once to give a normal perspective and a second time to indicate the finer detail. The detail shown in one sense is too great since the iso-flow contours vary slightly (and are shown as a constant on the plots). Generally speaking, in terms of the fume hoods, it can be said that fume hoods 10 and 14 draft far better than fume hood 15, and that only LDA gave useful information.

3.3. Room Aerodynamics

The room aerodynamics is best summarized by viewing the VHS video tape included with this report. The room aerodynamics was dominated by a recirculating flow set up by a wall-mounted electric heater that had a powerful fan unit. The sketch in figure 17 indicates the rough positioning of several room vortices. However, the full three-dimensional nature of the room air flow is demonstrated in the video tape.

3.4. Gas Concentration Measurements

The gas concentration measurements were performed by Hydro Research personnel[1] and the results are given in table 10 and the iso-concentration profiles are plotted at the three elevations for the two room conditions in figures 11 through 16. Examining Figure 12, iso-concentration contours for case 1, elevation 5 feet, one may see that a high concentration gradient exists in the region of the "Hydrogen Isotope Separation Facility" (HISF). A somewhat higher gradient exists at floor level (Figure 11) and this shifts somewhat as the flow approaches the ceiling. The lower concentration gradient (or spread out contours) near the bottom of Figure 12 are indicative of a room air vortex being

[1] Since this segment of the experiment was beyond our control we are only offering an interpretation of the data.

set up by the fan in a wall mounted electric heater. Also it can be seen from the same figure that the gradients fall off on the left side of the figure, corresponding to fume hood #14, and in the bottom right hand corner corresponding to fume hood #10. This augurs well with the results given in VHS tape included with this report. The gas concentration survey was repeated at a later date[2] (case 2) when the ambient weather conditions had warmed up. Thus this series of runs (illustrated in Figures 14 to 16) did not have the wall mounted electric heater driving the room air currents. In this case though the room concentrations are much lower than previously recorded and it is the fume hoods (number 10 and 14) that dominate the room air current flow. The dead air zone behind the HISF has become somewhat smaller (see Figure 15) and generally the room appears to show better ventilation.

It should be noted that trying to interpret a three-dimensional flow field from three planes of data is difficult and that the method of presentation in the video tape leaves a clearer impression of the flow field and its characteristics.

[2] By this time Kings Engineering had left the Hydro site and so have no verification data for case 2.

CHAPTER 4

RECOMMENDED TECHNIQUES AND EQUIPMENT

4.1. Recommended Method for Flow Rate Determination

Usage of a HWA for the low velocities encountered in the fume hood flows is difficult at best since the sensor must be calibrated before and after a set of traverses. This is necessary to check against drift and calibration shifts due to contamination on the sensor surface. Also, these sensors are extremely fragile since any mechanical contact with the tungsten filament will break it. Further, since this system would likely be calibrated against a LDA system anyway, there seems little point in adopting this technology. In one sense it can be stated that LDA is not just the preferred method but rather the only technology easily applicable to these flows without other support methods. Integrating a point-by-point traverse taken across a duct or fume hood by a LDA system is the preferred method for flow rate determination. This conclusion is based on the ease of taking measurements, linearity of the device, and lack of calibration requirements. Since recent advances have seen the compaction of these systems and reduced operator system operating knowledge of the associated electronics systems, we feel that LDA has transitioned from a laboratory method to a production measurement technique.

4.2. Recommended Method for Room Aerodynamics

Based on the success of using smoke generation and a video system, this system is recommended for making room aerodynamic studies. This method allows for dynamic condition changes such as the opening and closing of doors, and it can yield quantitative information with a video camera equipped with a stop watch function such as the unit used in this study. The smoke was generated with parafin oil and thus doesn't have any harmful effects, except in extreme concentrations. Further, this system has real speed advantages over gas sampling techniques because there is no need to establish a global gas concentration gradient in the room in question. The other difficulty with gas

sampling measurements is that while the global concentration gradient is set with a time scale related to the diffusion velocity (which is very small), any disturbance that upsets the local concentration gradient will see the effect of this propagate with the room velocity. The recovery from this perturbation though will proceed through the diffusion time scale. Thus any perturbation will take an inordinate length of time to decay. As added incentive the cost of the equipment used was approximately one fifth the cost of a single gas analysis system.

4.3. LDA System Recommendation

4.3.1. Fiber Optic Probe

It should be noted that the equipment used in this study was a hybrid of OEI[1] and TSI[2] equipment. This equipment, although seemingly bulky and cumbersome, best suits the wide range of applications it has been used on over the last seven plus years by the group[3] it was leased from. Given that the target application for the system recommended here, is far more restrictive and somewhat different, a less versatile system is specified. The system envisaged is centered around a fiber optic probe with a remotely mounted laser and photomultiplier tube. The probe operates in the back scatter mode and will use an Argon Ion laser as its light source. This choice was based on the necessity of remote mounting of the probe and making velocity traverses across the openings of various ducts high above ground level. While this will provide a base system to work on, several options must be considered. If very low (less than 15 cm/sec.) velocities or reverse flows are encountered, then a Bragg cell shifting system should be employed. However this leads to an extra complication in so far as fiber optic probes are concerned in that two single-mode fibers must be used in lieu of one single mode-fiber. Multi-mode fibers normally are the preferred way of transmitting light, however they do not preserve polarization. Single-mode fibers do preserve polarization, however they are very small in diameter and require accurate alignment in order to direct light efficiently. Given this extra complication (the addition of another fiber to align) and the fact that velocity directions may be

[1] Opto-Electronische-Instrumente

[2] Thermo Systems Incorporated

[3] Laser Doppler Anemometry Laboratory UTME

determined with small amounts of smoke injection, we are recommending a fiber optic probe system without Bragg cell shifting for simplicity and ease of use. The fiber optic probe system recommended is a TSI[4] Fiber Optic LDV Probe System, Model 9720 with 135mm objective lens. The specifications for this probe and others are appended to this report. The rationale for picking this particular system is that it has an acceptably small probe body size (25mm diameter) and has the longest available objective lens (135mm). This probe only measures one component of velocity but may be conveniently rotated to measure a second component of velocity. More expensive systems allow for the simultaneous measurement of two velocities. However, additional operator attention and complexity make these systems less desirable.

This probe system should be connected to an Argon Ion Laser of 50mW to 1 watts. Here some options are available in the size and type of laser. The higher power Argon Ion lasers all require water cooling which makes portability difficult at best. However there are several aircooled Argon Ion lasers such as the Lexel Model 65[5] which are more portable since only a power cord has to be spooled out to allow movement of the laser.

4.3.2. LDA Electronics

While the choice of the probe system and a laser was mandated by portability and measurement principles, the selection process for electronics packages is driven largely by the degree to which the signal acquisition and reduction process may be automated. In this regard an Intelligent Flow Analyzer (IFA) Model 550 system is recommended which is the very latest in signal analysis equipment. This system, the descriptive literature for which is appended to this report (Appendix E), is driven by an IBM PC and operates in a hands-off mode giving user-independent results. Essentially this electronics package contains all the necessary bandpass filters and does its own automatic data validation. The results are stored, through an interface, into a PC and then may be displayed during the acquisition process or accumulated and displayed later. In this regard the IFA Model 550 and a PC together can be

[4] Please note that Kings Engineering Associates has no affiliation with Thermo Systems Inc..

[5] Lexel is the preferred laser manufacturer of TSI; however the laser should be purchased from the LDA manufacturer to ensure correct interfacing of the system and system checkout before shipping.

considered to comprise a fully automated, operator interaction-free system. The software written in the execution of the contract has been tailored to accommodate this electronics system to the extent of the information we have at our disposal, and is found in Appendix D.

4.3.3. Manpower and Procedures

Based on the information on hand, it is expected that one person could easily operate the recommended system in so far as data acquisition and reduction is concerned. An averaging time of one minute per point is adequate to ensure an accurate local mean and this coupled with a 36-point traverse would mean that a single flow rate measurement should take about 40 minutes per location, not including traverse times[6].

The errors involved with using LDA for flow rate determination are minimal, with the maximum error coming from the integration over the grid of points. However for the flows encountered in this study, the velocity profiles were very flat and there was little to be gained from increasing the number of points beyond the values used.

The procedures for operating the LDA system will be those set down by the equipment manufacturers.

[6] Details concerning a traversing mechanism are beyond the scope of this work.

APPENDIX A
EQUIPMENT USED

Characteristics of LDA System

Laser:

Type:	He-Ne
Output Power:	15 mw
Wavelength:	632.8 nm
e^{-2}	1.10 mm

Transmitting Optics:

Type:	OEI
Frequency Shifting:	Bragg Cells Both Beams
Frequency Shifts:	0,0.2,0.7 Mhz.
Beam Separation Prior to Focusing:	50 mm
Focal Length of Front Lens:	291.4mm
Beam convergence angle:	9.81^0 (2ϕ)

Receiving Optics:

Type:	TSI
Focal Length of receiving lens:	242.2 mm
Photomultiplier:	TSI 962

Measuring Volume Lengths (e^{-2} points)

Along optical axis:	2.50 mm
Normal to optical axis:	0.214 mm

Fringes:

Spacing:	3.702 µm
Number in e^{-2} measuring volume:	58

Bandpass Filter:

Type:	7th. order Chebyshev
Model:	OEI LD-E-310
Skirt Slope:	>67 dB/octave
High-Pass ranges:	0.05,0.1,0.2,0.5 MHz
Low-Pass ranges:	0.5,1,2 MHz

Trackers:

Type:	Cambridge Consultants CC04 TSI Model 1090
Ranges:	7 KHz. - 16 MHz.(CC04) 2 KHz. - 2.5 MHz. (1090)

HWA Equipment

Bridge:	
Type:	Constant Temperature
Model:	DISA 55M
Voltmeter:	
Type:	Digital
Model:	DISA 55D31
Probe Holder:	
Type:	90^0
Model:	DISA
Sensor:	
Type:	Hot Wire (Tungsten)
Model:	DISA 55P11

APPENDIX B
FIGURES CITED

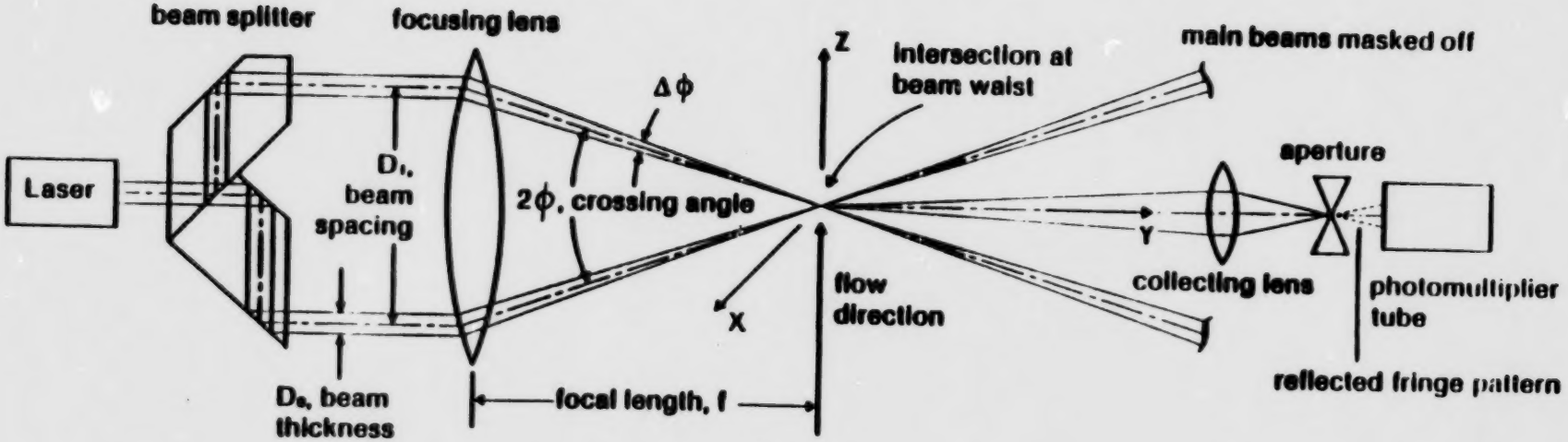

Figure 1.1: Schematic of Forward-Scatter LDA
-Page B.1a-

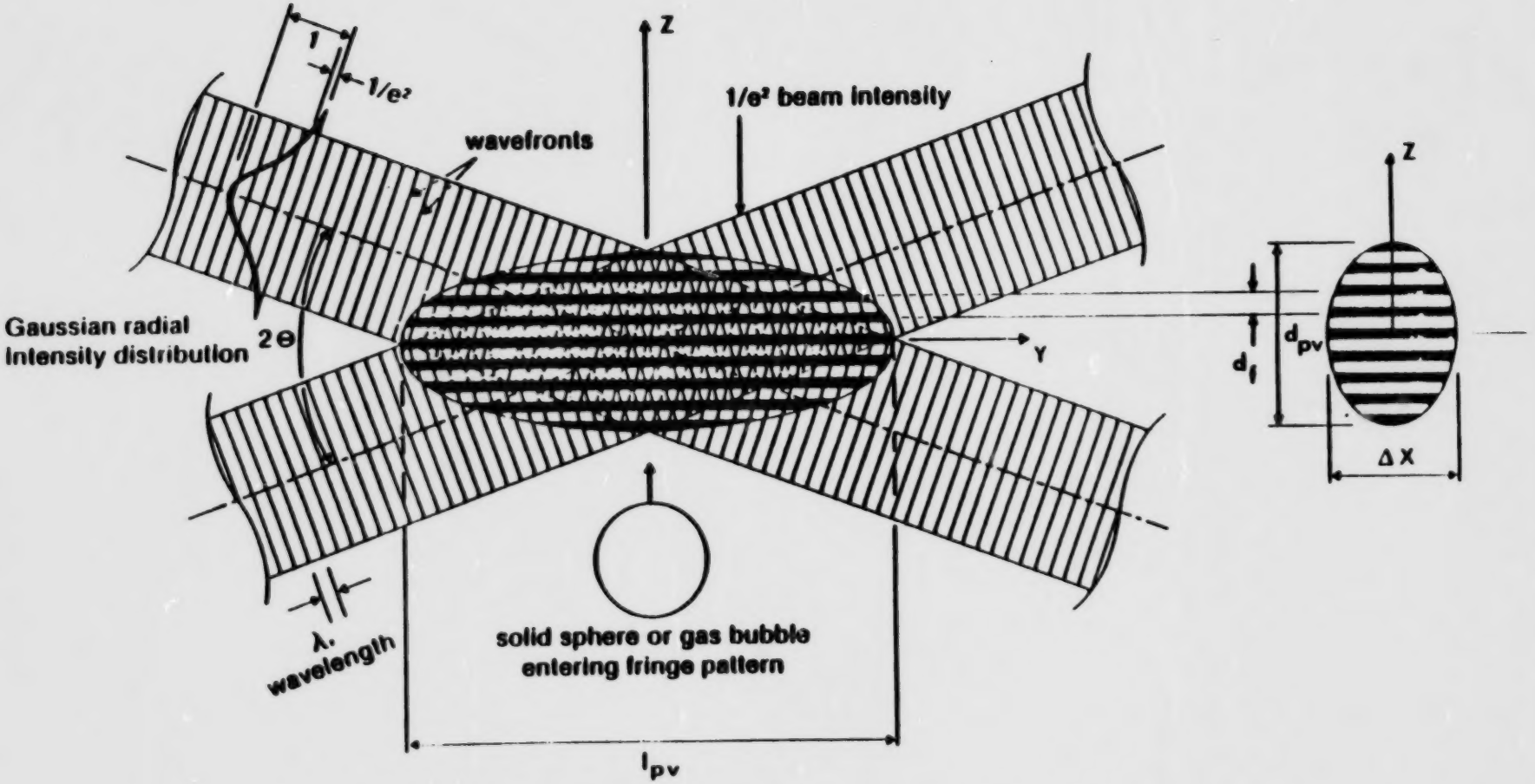

Figure 2.1: LDA Fringe Patterns
-Page B.1b-

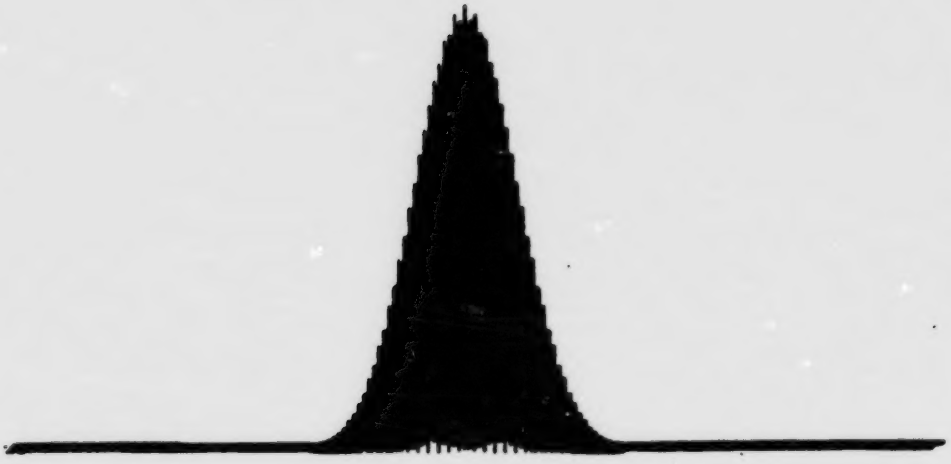

Figure 2.2: Unfiltered Doppler Burst

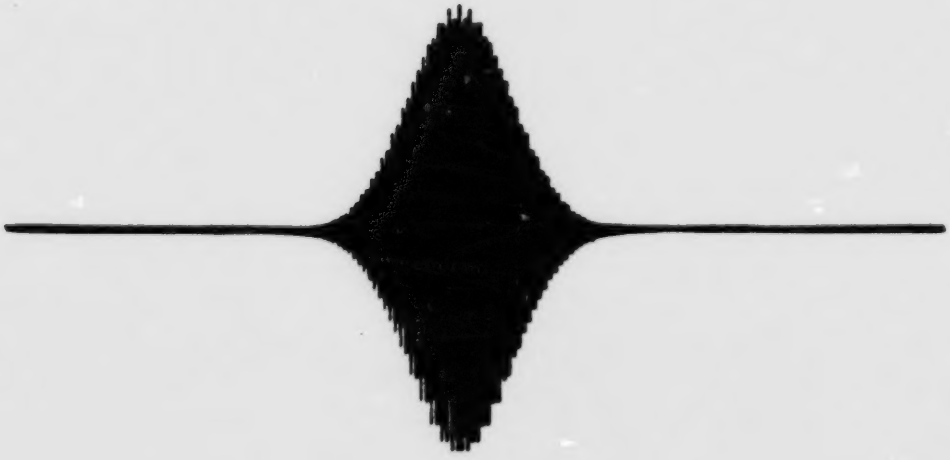

Figure 2.3: High Pass Filtered Doppler Burst
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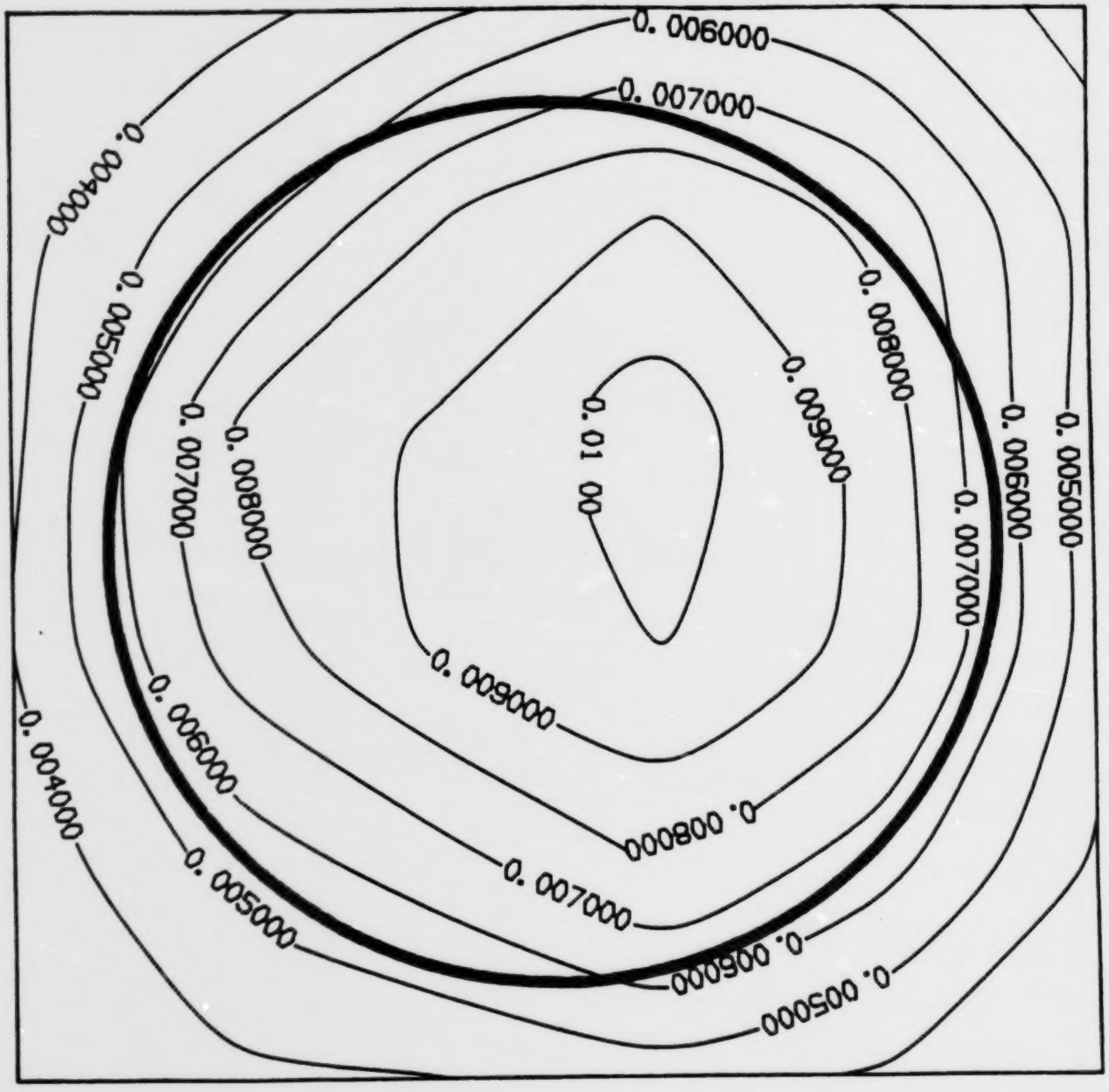

Figure 3: Iso-Flow Rate Contours, Ventilator #9
-Page B.2-

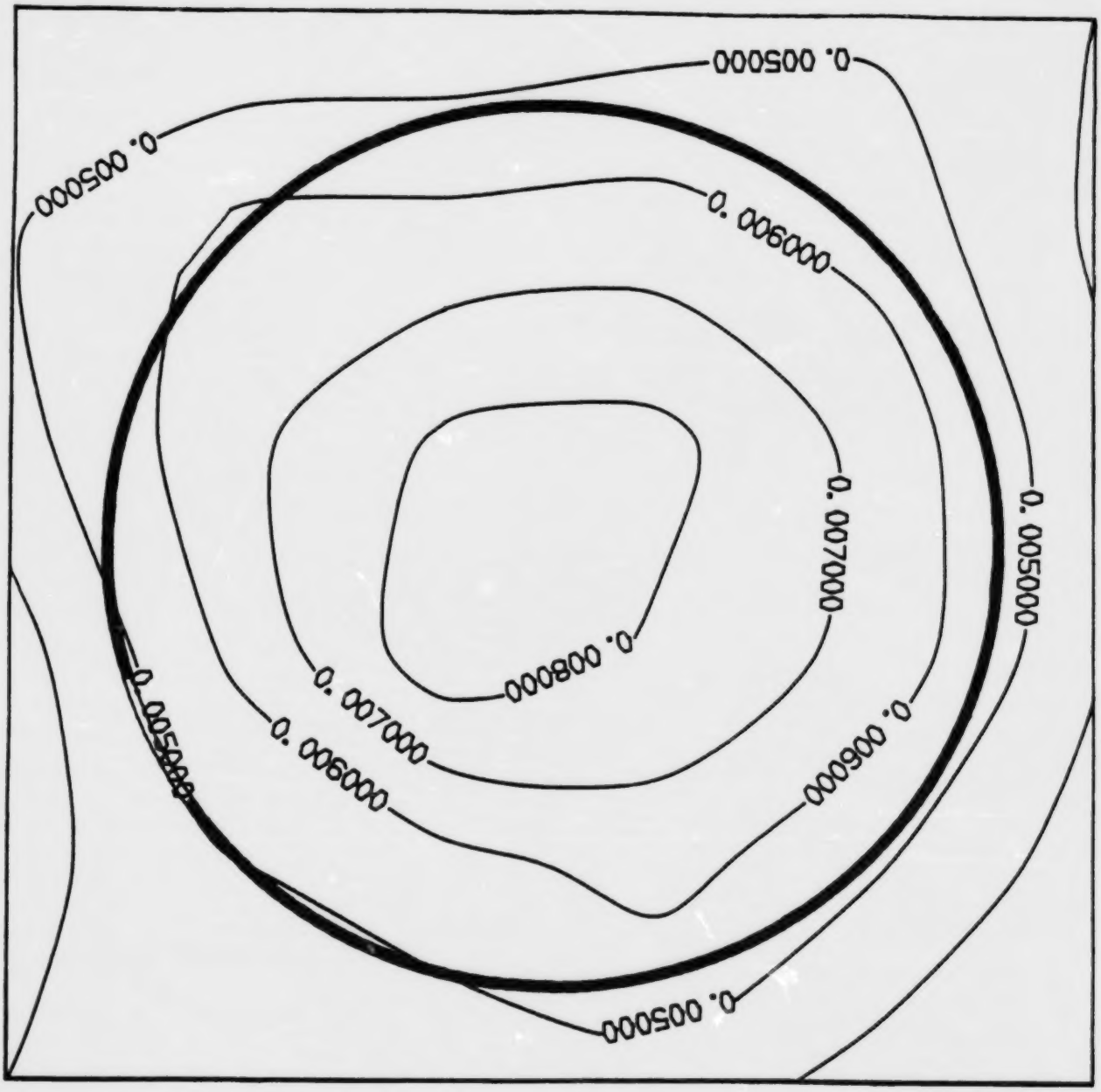

Figure 4: Iso-Flow Rate Contours, Ventilator #4,Condition A
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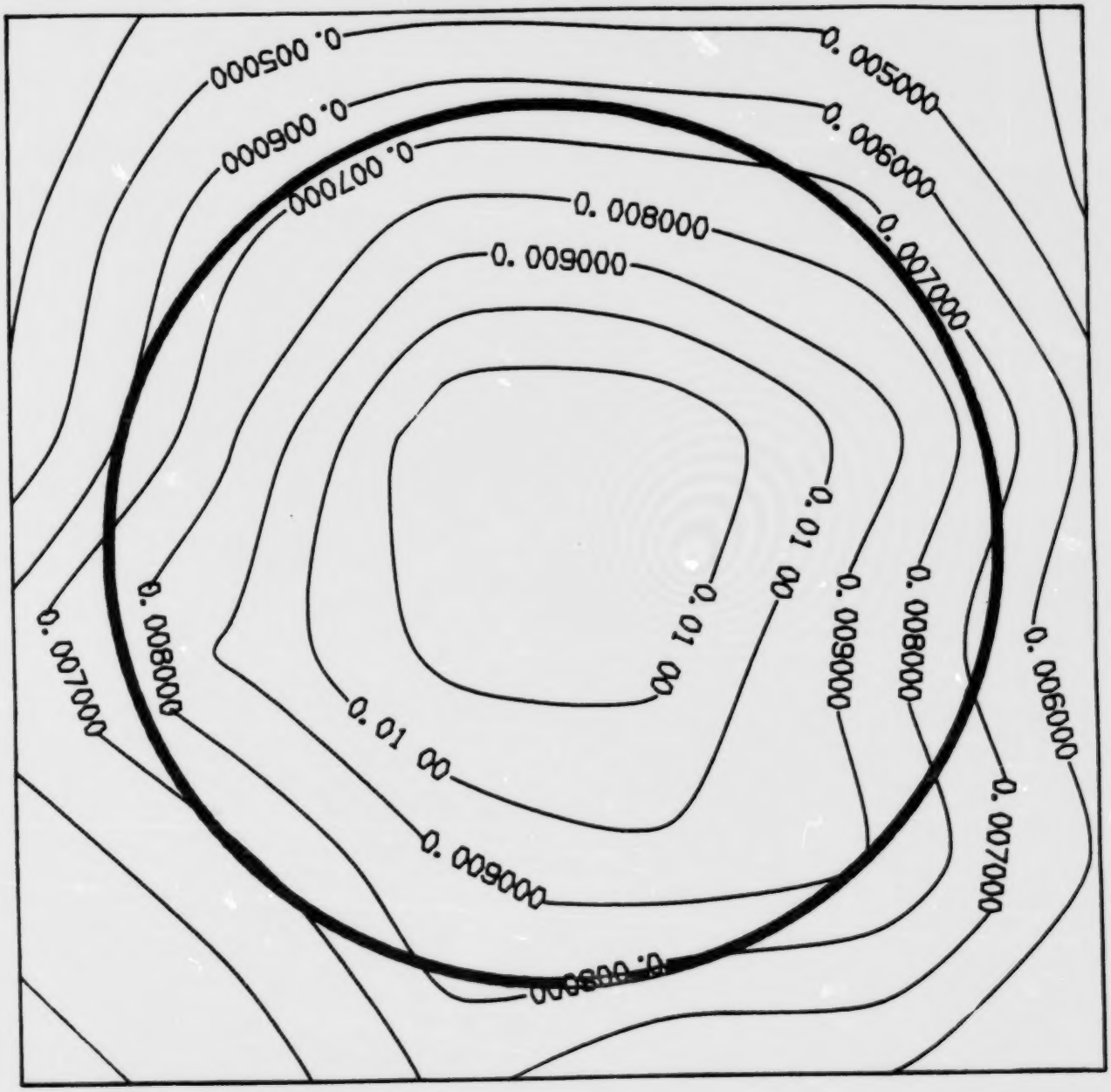

Figure 5: Iso-Flow Rate Contours, Ventilator #4,Condition B
-Page B.4-

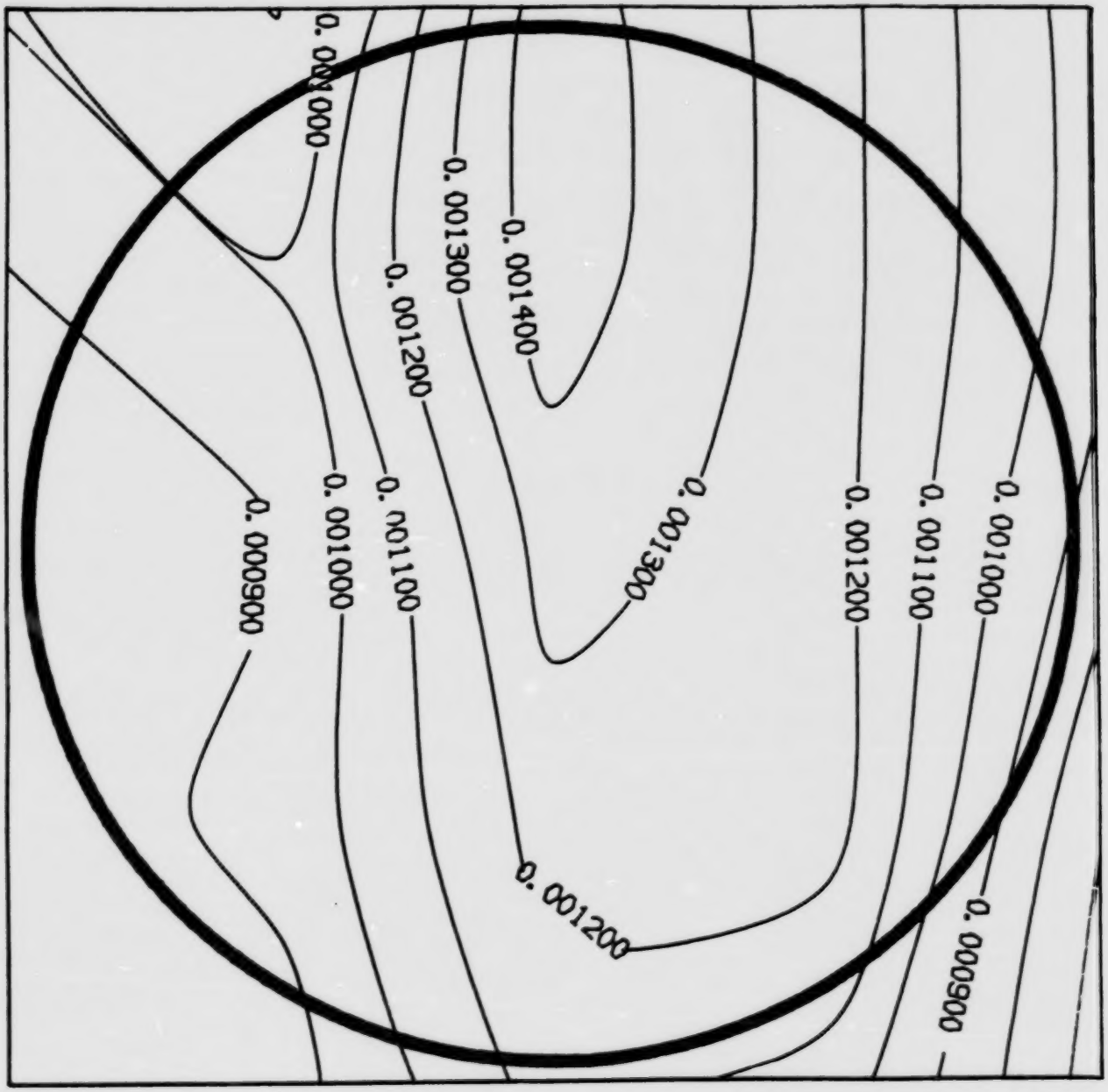

Figure 6: Iso-Flow Rate Contours, Fume Hood 15, Portal (i)
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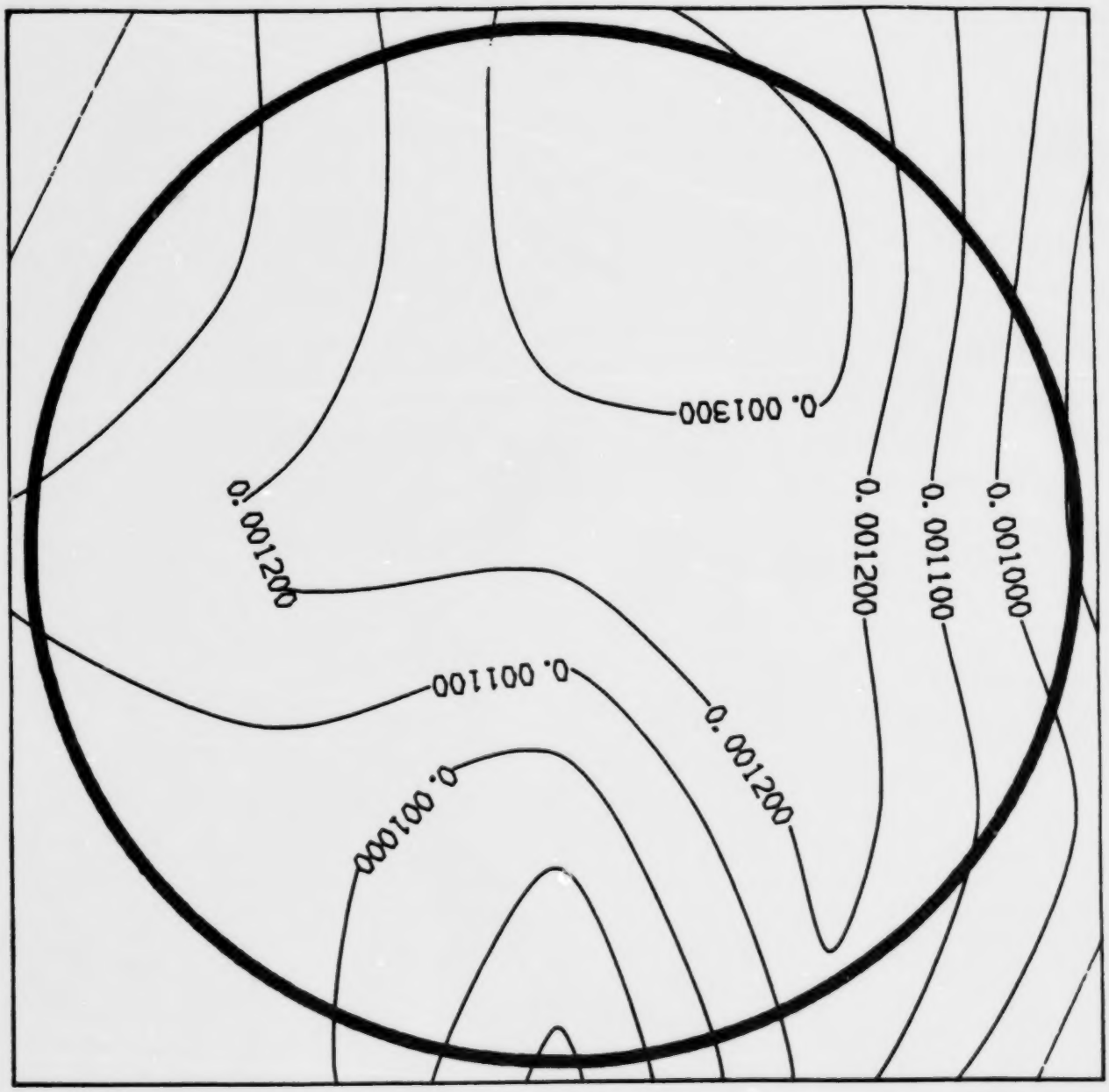

Figure 7: Iso-Flow Rate Contours, Fume Hood 15, Portal (ii)
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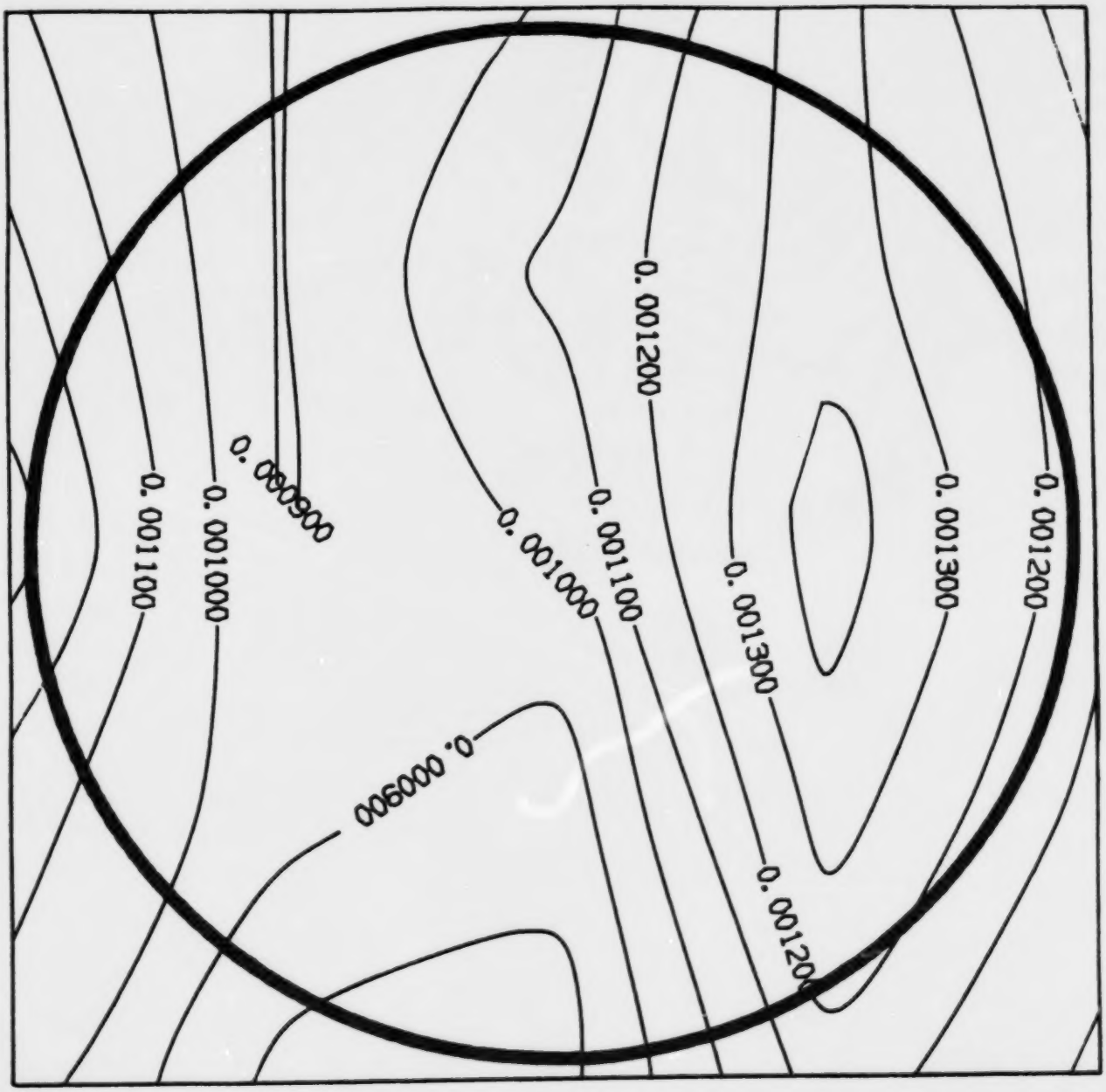
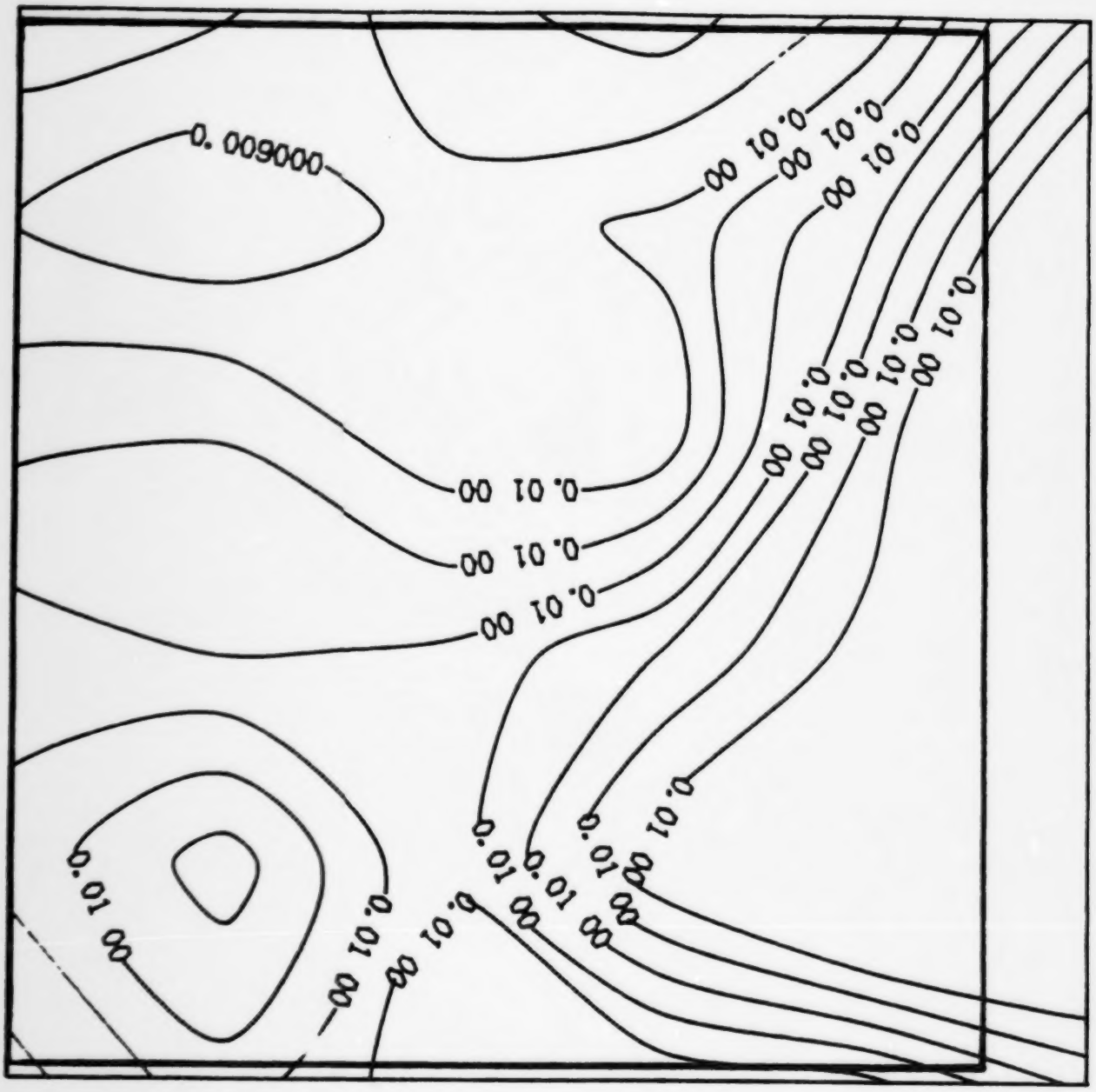


Figure 8: Iso-Flow Rate Contours, Fume Hood 15, Portal (iii)
-Page B.7-

Figure 9a: Iso-Flow Rate Contours, Fume Hood 14
Normal Perspective
-Page B.8a-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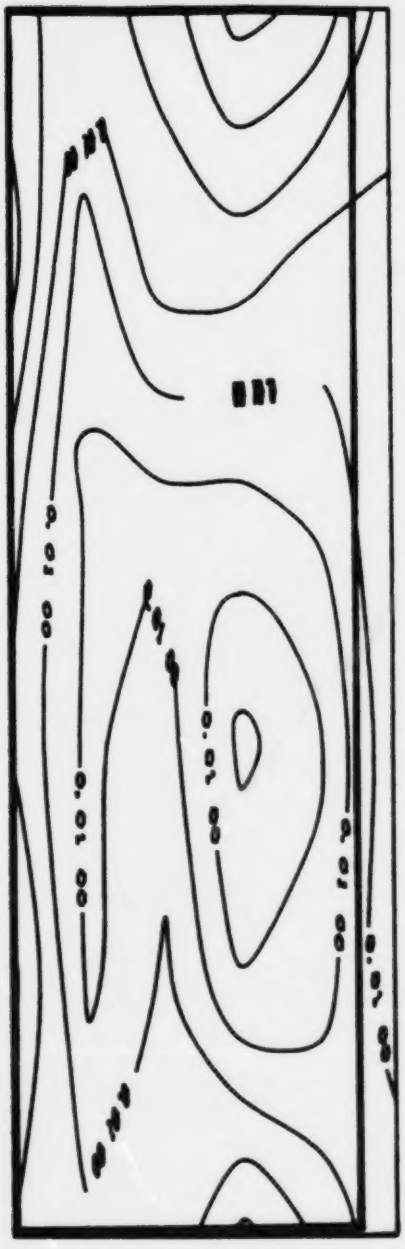

Figure 10a: Iso-Flow Rate Contours, Fume Hood 10
Normal Perspective
-Page B.9a-

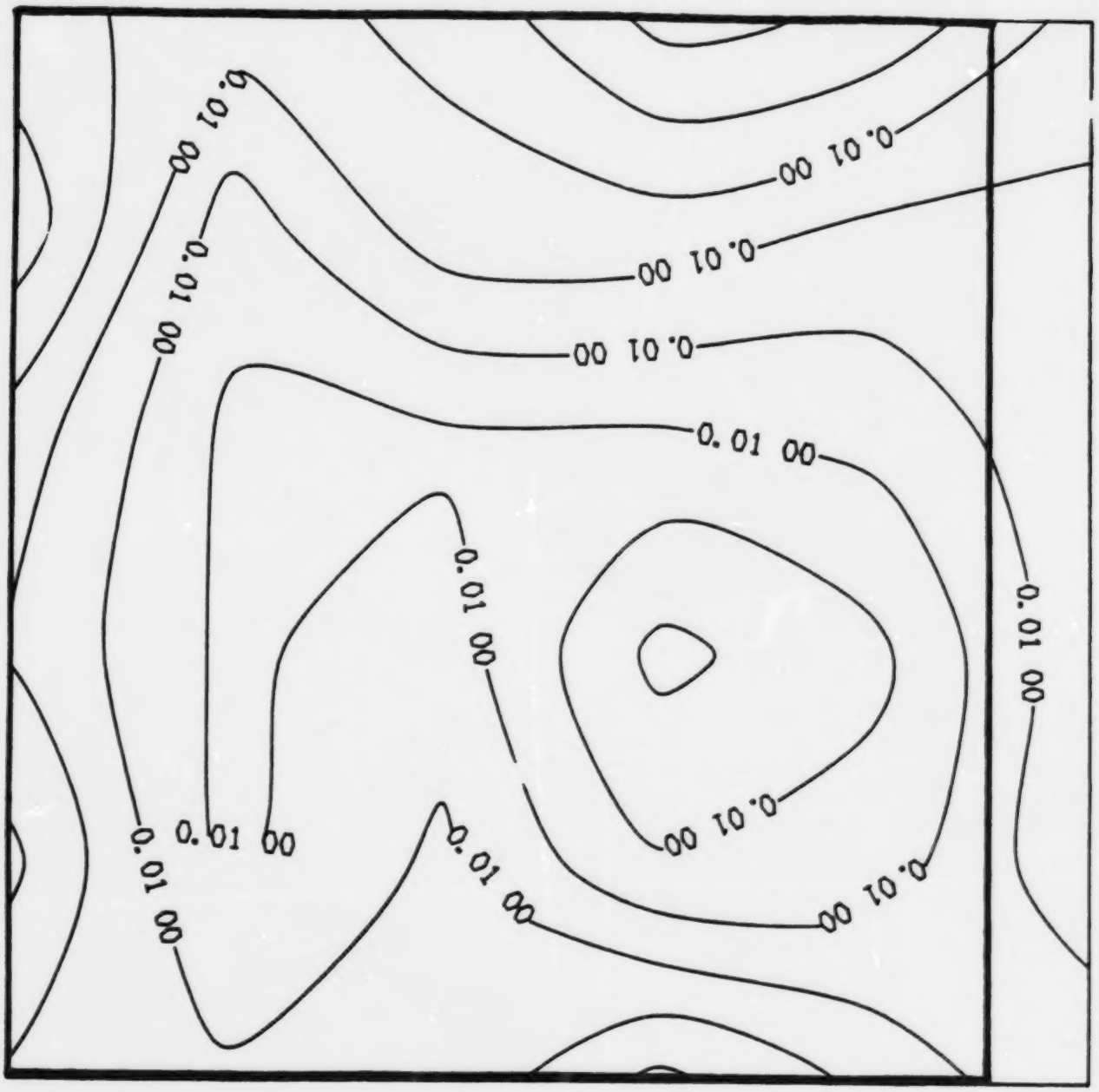

Figure 10b: Iso-Flow Rate Contours, Fume Hood 10
-Page B.9b-

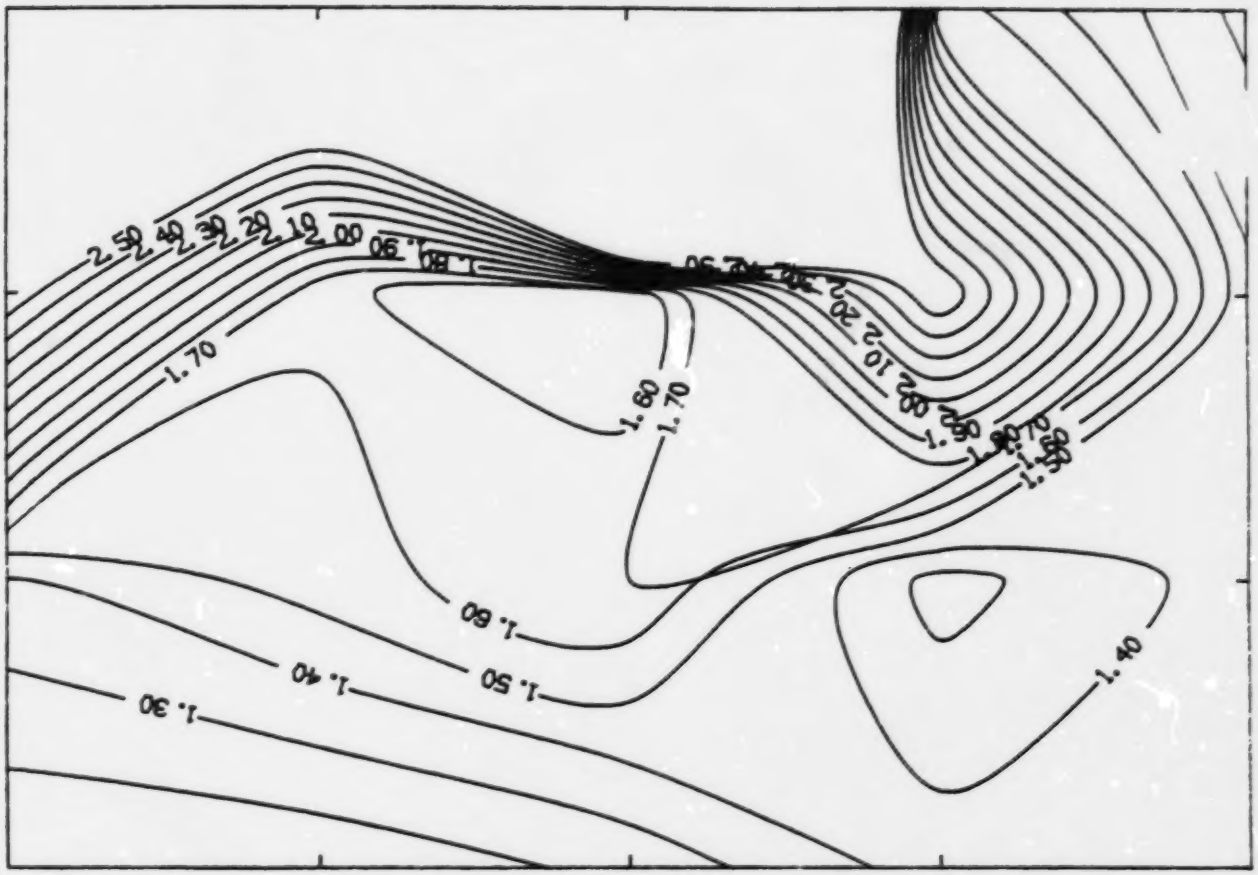

Figure 11: Iso-Concentration Contours, Case 1, Elevation 1
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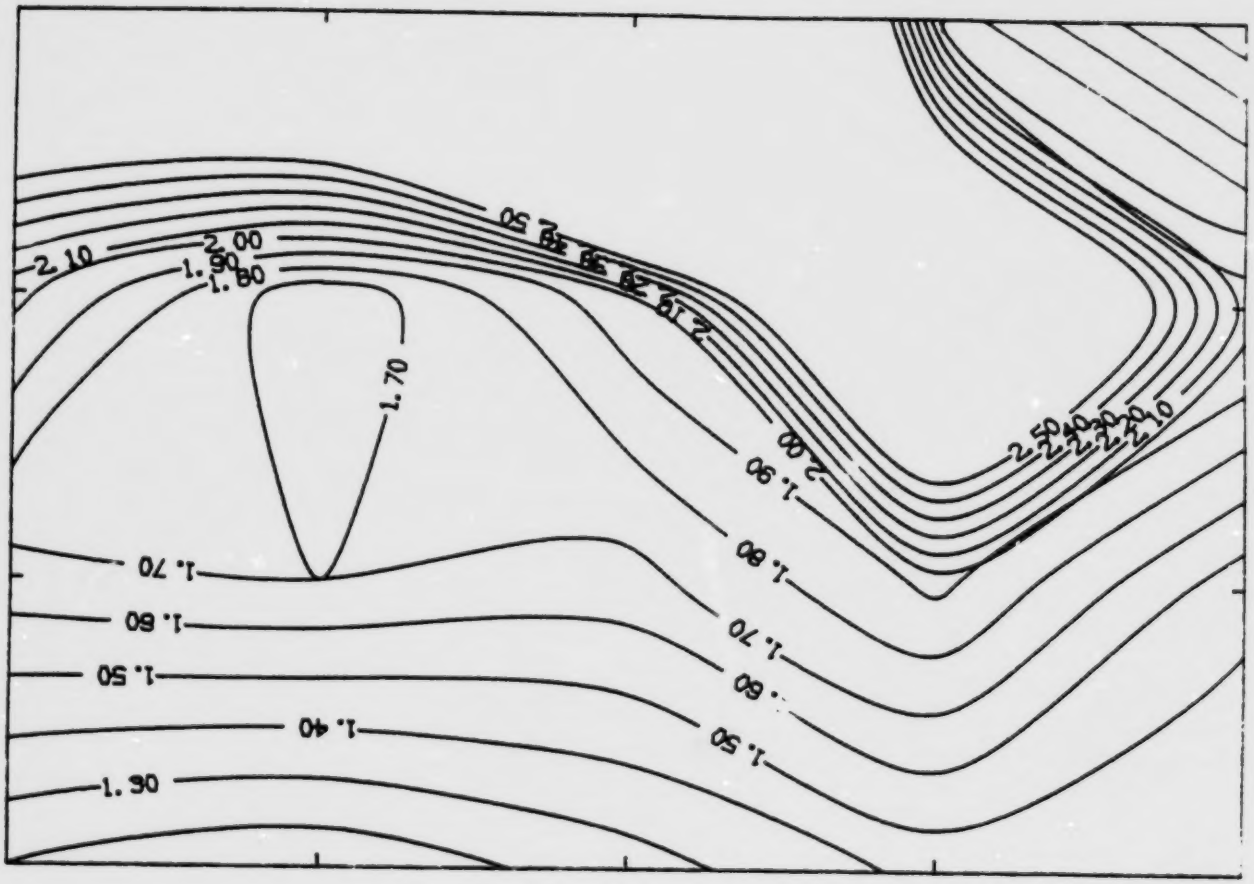

Figure 12: Iso-Concentration Contours, Case 1, Elevation 5
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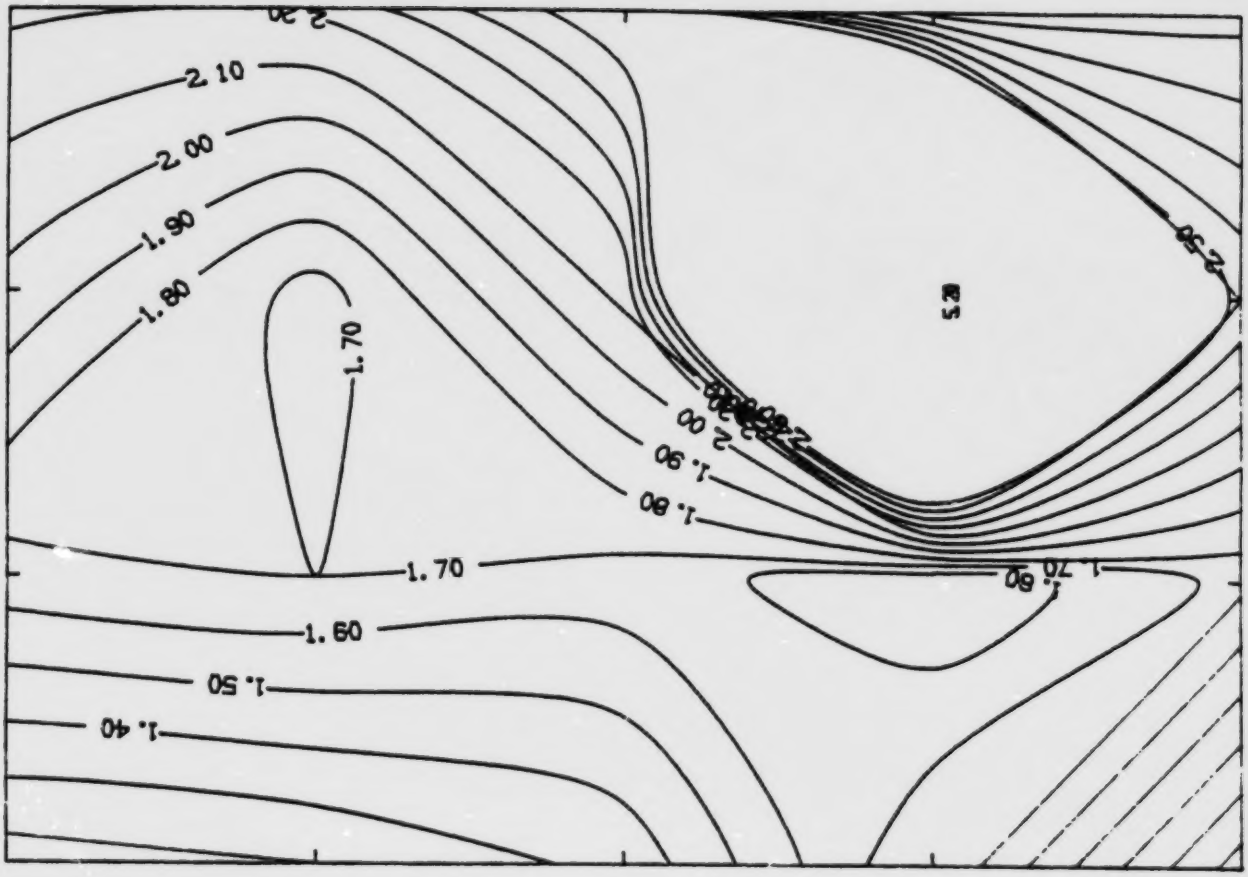

Figure 13: Iso-Concentration Contours, Case 1, Elevation 10
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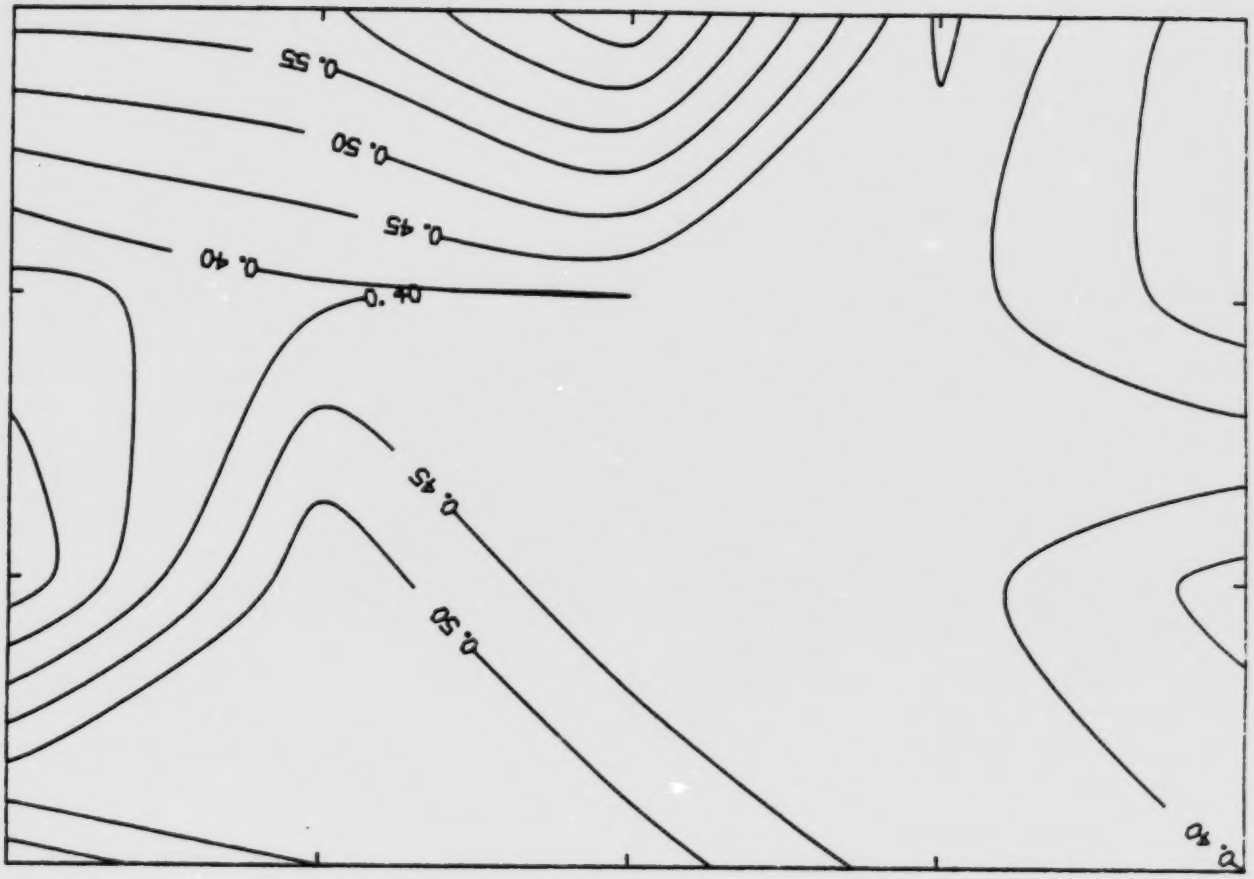

Figure 14: Iso-Concentration Contours, Case 2, Elevation 1
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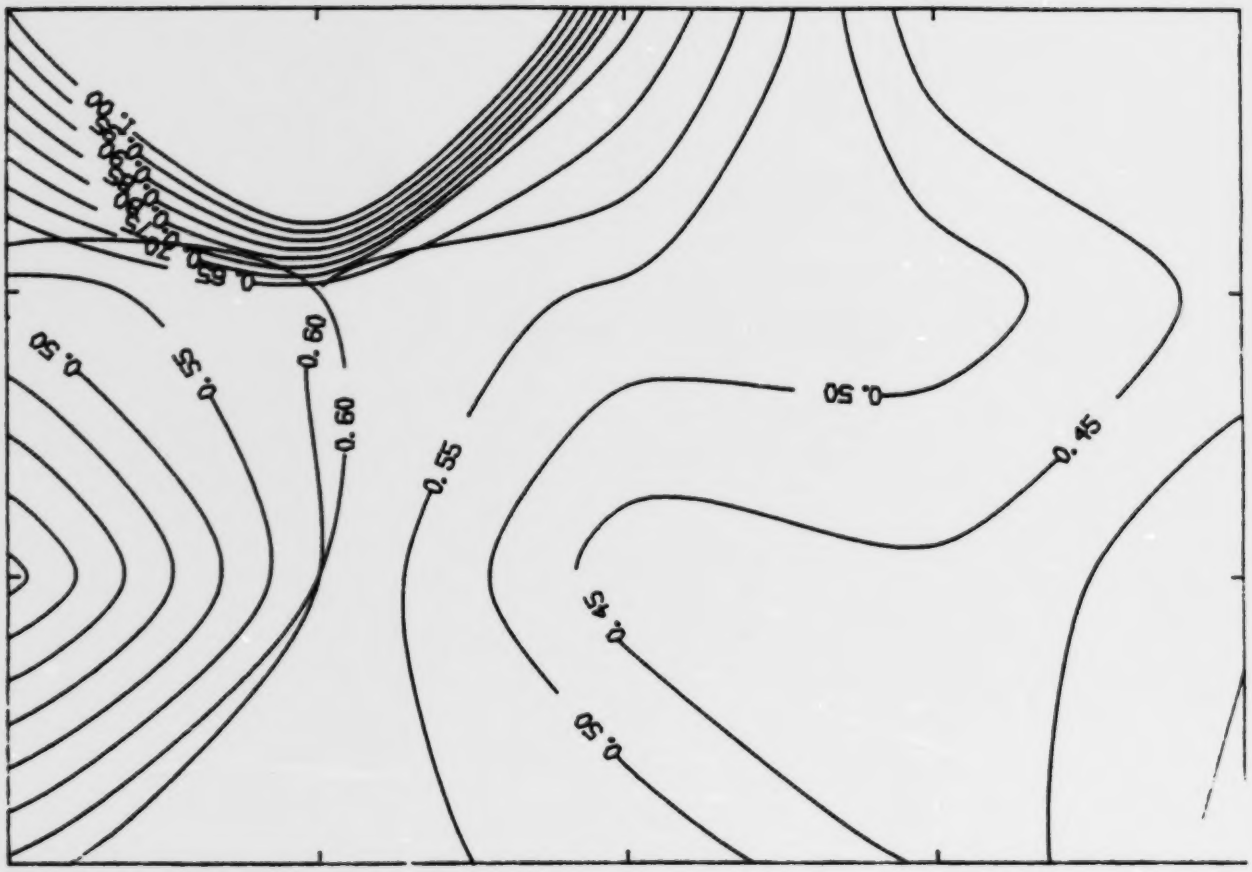

Figure 15: Iso-Concentration Contours, Case 2, Elevation 5
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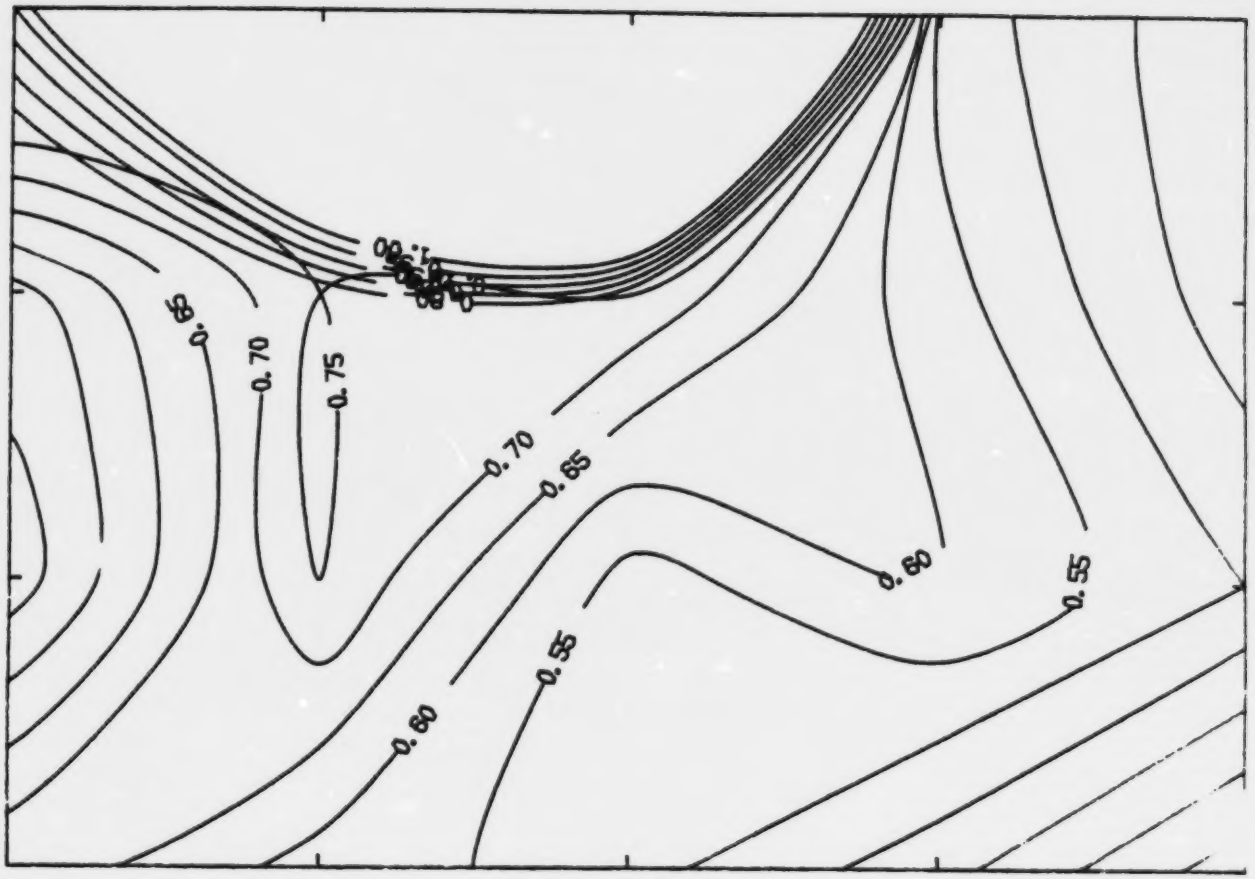

Figure 16: Iso-Concentration Contours, Case 2, Elevation 10
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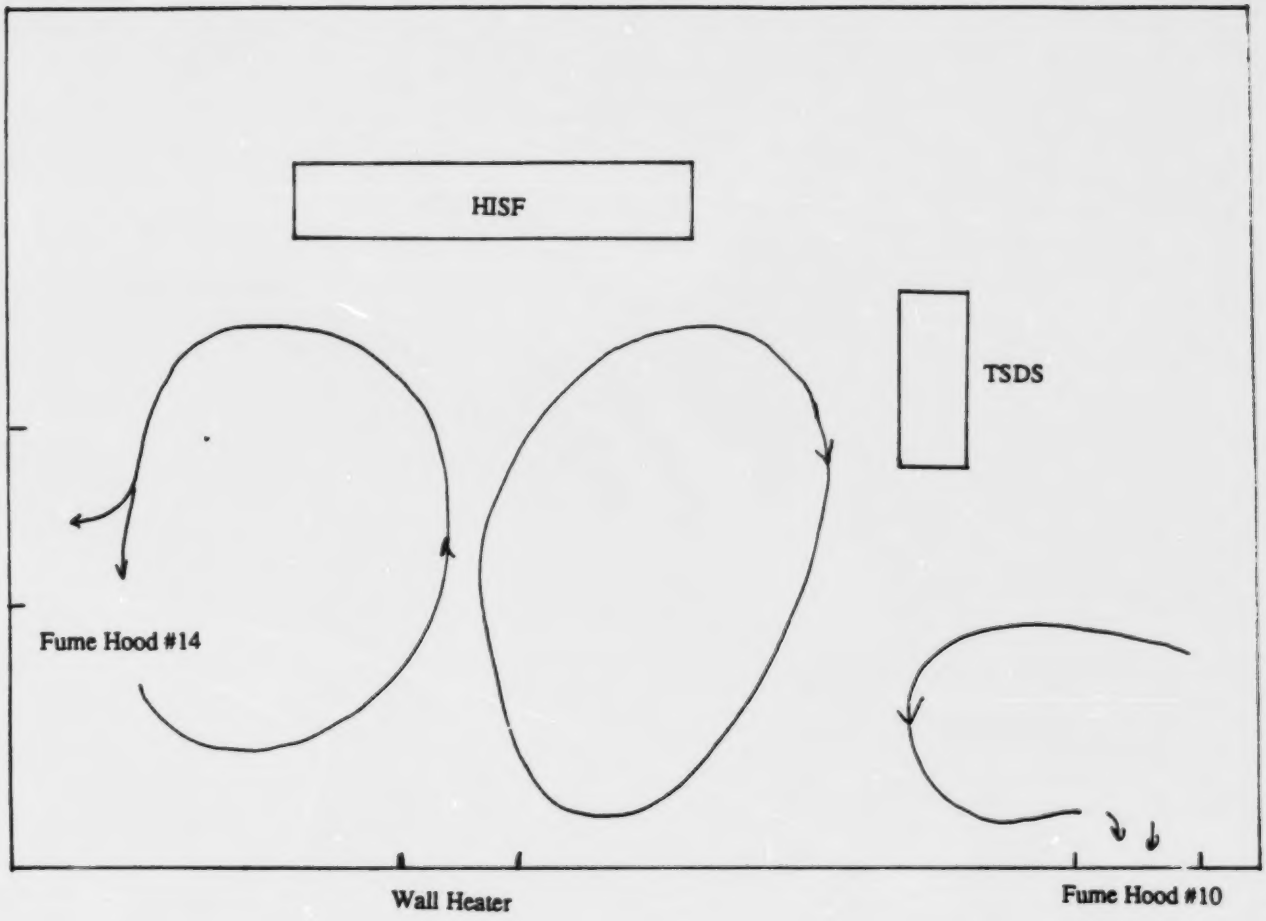


Figure 17: Room Air Movements from Video Study
-Page B.16-

APPENDIX C
TABULATED DATA

Condition Table			
Device#	Type	Position(a)	Position(b)
1	V	O	O
2	V	C	C
3	V	C	C
4	V	O	O
5	V	C	C
6	V	C	C
7	V	C	C
8	V	C	C
9	V	O	C
10	F	O	C
11	F	O	C
12	V	C	C
13	F	O	O
14	F	O	O
15	F	O	C
16	F	O	O

Legend:

V - Ventilator

F - Fume Hood

O - Open

C - Closed

Table 1: Room Device Numbers and Position for Conditions A & B

*** FLOW RESULTS FOR vent#9 ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.280	1.04	0.37e-02	2.90	0.54	0.19e-02
0.00	6.00	0.270	1.00	0.36e-02	3.02	0.89	0.32e-02
0.00	12.00	0.360	1.33	0.48e-02	3.18	1.55	0.56e-02
0.00	18.00	0.440	1.63	0.59e-02	3.25	1.93	0.70e-02
0.00	24.00	0.380	1.41	0.51e-02	3.22	1.76	0.64e-02
0.00	30.00	0.270	1.00	0.36e-02	3.14	1.36	0.49e-02
6.00	0.00	0.270	1.00	0.36e-02	2.98	0.76	0.27e-02
6.00	6.00	0.420	1.55	0.56e-02	3.13	1.32	0.47e-02
6.00	12.00	0.600	2.22	0.80e-02	3.34	2.51	0.90e-02
6.00	18.00	0.680	2.52	0.91e-02	3.38	2.80	0.10e-01
6.00	24.00	0.580	2.15	0.77e-02	3.33	2.44	0.88e-02
6.00	30.00	0.350	1.30	0.47e-02	3.24	1.88	0.68e-02
12.00	0.00	0.280	1.04	0.37e-02	3.10	1.19	0.43e-02
12.00	6.00	0.600	2.22	0.80e-02	3.27	2.05	0.74e-02
12.00	12.00	0.690	2.55	0.92e-02	3.40	2.96	0.11e-01
12.00	18.00	0.790	2.92	0.11e-01	3.42	3.12	0.11e-01
12.00	24.00	0.650	2.41	0.87e-02	3.36	2.65	0.96e-02
12.00	30.00	0.340	1.26	0.45e-02	3.28	2.11	0.76e-02
18.00	0.00	0.300	1.11	0.40e-02	3.17	1.50	0.54e-02
18.00	6.00	0.550	2.04	0.73e-02	3.33	2.44	0.88e-02
18.00	12.00	0.690	2.55	0.92e-02	3.41	3.04	0.11e-01
18.00	18.00	0.750	2.78	0.10e-01	3.41	3.04	0.11e-01
18.00	24.00	0.650	2.41	0.87e-02	3.39	2.88	0.10e-01
18.00	30.00	0.340	1.26	0.45e-02	3.25	1.93	0.70e-02
24.00	0.00	0.250	0.93	0.33e-02	3.14	1.36	0.49e-02
24.00	6.00	0.400	1.48	0.53e-02	3.27	2.05	0.74e-02
24.00	12.00	0.500	1.85	0.67e-02	3.31	2.31	0.83e-02
24.00	18.00	0.610	2.26	0.81e-02	3.28	2.11	0.76e-02
24.00	24.00	0.480	1.78	0.64e-02	3.20	1.66	0.60e-02
24.00	30.00	0.290	1.07	0.39e-02	3.10	1.19	0.43e-02
30.00	0.00	0.260	0.96	0.35e-02	3.03	0.92	0.33e-02
30.00	6.00	0.280	1.04	0.37e-02	3.11	1.23	0.44e-02
30.00	12.00	0.300	1.11	0.40e-02	3.15	1.41	0.51e-02
30.00	18.00	0.340	1.26	0.45e-02	3.08	1.11	0.40e-02
30.00	24.00	0.290	1.07	0.39e-02	3.00	0.82	0.30e-02
30.00	30.00	0.290	1.07	0.39e-02	2.96	0.70	0.25e-02

LDA - Average velocity = 1.63 m/s, Total flow rate = 0.211 m^3/s

HWA - Average velocity = 1.82 m/s, Total flow rate = 0.236 m^3/s

Table 2: LDA and HWA Data for Ventilator #9
-Page C.3-

*** FLOW RESULTS FOR vent#4A ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.300	1.11	0.40e-02	2.95	0.67	0.24e-02
0.00	6.00	0.300	1.11	0.40e-02	3.06	1.03	0.37e-02
0.00	12.00	0.310	1.15	0.41e-02	3.11	1.23	0.44e-02
0.00	18.00	0.340	1.26	0.45e-02	3.06	1.03	0.37e-02
0.00	24.00	0.360	1.33	0.48e-02	2.98	0.76	0.27e-02
0.00	30.00	0.300	1.11	0.40e-02	2.90	0.54	0.19e-02
6.00	0.00	0.370	1.37	0.49e-02	3.03	0.92	0.33e-02
6.00	6.00	0.460	1.70	0.61e-02	3.15	1.41	0.51e-02
6.00	12.00	0.470	1.74	0.63e-02	3.22	1.76	0.64e-02
6.00	18.00	0.480	1.78	0.64e-02	3.20	1.66	0.60e-02
6.00	24.00	0.420	1.55	0.56e-02	3.11	1.23	0.44e-02
6.00	30.00	0.290	1.07	0.39e-02	2.95	0.67	0.24e-02
12.00	0.00	0.350	1.30	0.47e-02	3.05	0.99	0.36e-02
12.00	6.00	0.500	1.85	0.67e-02	3.18	1.55	0.56e-02
12.00	12.00	0.610	2.26	0.81e-02	3.26	1.99	0.72e-02
12.00	18.00	0.620	2.29	0.83e-02	3.26	1.99	0.72e-02
12.00	24.00	0.500	1.85	0.67e-02	3.18	1.55	0.56e-02
12.00	30.00	0.320	1.18	0.43e-02	3.04	0.96	0.34e-02
18.00	0.00	0.270	1.00	0.36e-02	3.00	0.82	0.30e-02
18.00	6.00	0.460	1.70	0.61e-02	3.14	1.36	0.49e-02
18.00	12.00	0.650	2.41	0.87e-02	3.24	1.88	0.68e-02
18.00	18.00	0.590	2.18	0.79e-02	3.27	2.05	0.74e-02
18.00	24.00	0.500	1.85	0.67e-02	3.23	1.82	0.65e-02
18.00	30.00	0.310	1.15	0.41e-02	3.10	1.19	0.43e-02
24.00	0.00	0.270	1.00	0.36e-02	2.94	0.64	0.23e-02
24.00	6.00	0.370	1.37	0.49e-02	3.04	0.96	0.34e-02
24.00	12.00	0.420	1.55	0.56e-02	3.18	1.55	0.56e-02
24.00	18.00	0.480	1.78	0.64e-02	3.24	1.88	0.68e-02
24.00	24.00	0.380	1.41	0.51e-02	3.20	1.66	0.60e-02
24.00	30.00	0.260	0.96	0.35e-02	3.09	1.15	0.41e-02
30.00	0.00	0.300	1.11	0.40e-02	2.85	0.43	0.15e-02
30.00	6.00	0.340	1.26	0.45e-02	2.98	0.76	0.27e-02
30.00	12.00	0.330	1.22	0.44e-02	3.12	1.27	0.46e-02
30.00	18.00	0.350	1.30	0.47e-02	3.17	1.50	0.54e-02
30.00	24.00	0.270	1.00	0.36e-02	3.11	1.23	0.44e-02
30.00	30.00	0.240	0.89	0.32e-02	2.99	0.79	0.28e-02

LDA - Average velocity = 1.45 m/s, Total flow rate = 0.188 m^3/s

HWA - Average velocity = 1.25 m/s, Total flow rate = 0.162 m^3/s

Table 3: LDA and HWA Data for Ventilator #4, Condition A
-Page C.4-

*** FLOW RESULTS FOR vent#4B ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.250	0.93	0.33e-02	3.04	0.96	0.34e-02
0.00	6.00	0.330	1.22	0.44e-02	3.13	1.32	0.47e-02
0.00	12.00	0.360	1.33	0.48e-02	3.20	1.66	0.60e-02
0.00	18.00	0.350	1.30	0.47e-02	3.15	1.41	0.51e-02
0.00	24.00	0.340	1.26	0.45e-02	3.05	0.99	0.36e-02
0.00	30.00	0.290	1.07	0.39e-02	2.96	0.70	0.25e-02
6.00	0.00	0.270	1.00	0.36e-02	3.11	1.23	0.44e-02
6.00	6.00	0.500	1.85	0.67e-02	3.24	1.88	0.68e-02
6.00	12.00	0.630	2.33	0.84e-02	3.33	2.44	0.88e-02
6.00	18.00	0.610	2.26	0.81e-02	3.31	2.31	0.83e-02
6.00	24.00	0.540	2.00	0.72e-02	3.19	1.61	0.58e-02
6.00	30.00	0.300	1.11	0.40e-02	3.02	0.89	0.32e-02
12.00	0.00	0.320	1.18	0.43e-02	3.12	1.27	0.46e-02
12.00	6.00	0.590	2.18	0.79e-02	3.28	2.11	0.76e-02
12.00	12.00	0.890	3.29	0.12e-01	3.37	2.73	0.98e-02
12.00	18.00	0.900	3.33	0.12e-01	3.37	2.73	0.98e-02
12.00	24.00	0.710	2.63	0.95e-02	3.28	2.11	0.76e-02
12.00	30.00	0.430	1.59	0.57e-02	3.12	1.27	0.46e-02
18.00	0.00	0.510	1.89	0.68e-02	3.10	1.19	0.43e-02
18.00	6.00	0.690	2.55	0.92e-02	3.25	1.93	0.70e-02
18.00	12.00	0.850	3.15	0.11e-01	3.36	2.65	0.96e-02
18.00	18.00	0.850	3.15	0.11e-01	3.39	2.88	0.10e-01
18.00	24.00	0.620	2.29	0.83e-02	3.33	2.44	0.88e-02
18.00	30.00	0.380	1.41	0.51e-02	3.22	1.76	0.64e-02
24.00	0.00	0.400	1.48	0.53e-02	2.96	0.70	0.25e-02
24.00	6.00	0.500	1.85	0.67e-02	3.14	1.36	0.49e-02
24.00	12.00	0.680	2.52	0.91e-02	3.33	2.44	0.88e-02
24.00	18.00	0.730	2.70	0.97e-02	3.37	2.73	0.98e-02
24.00	24.00	0.670	2.48	0.89e-02	3.34	2.51	0.90e-02
24.00	30.00	0.440	1.63	0.59e-02	3.22	1.76	0.64e-02
30.00	0.00	0.350	1.30	0.47e-02	2.92	0.59	0.21e-02
30.00	6.00	0.400	1.48	0.53e-02	3.10	1.19	0.43e-02
30.00	12.00	0.550	2.04	0.73e-02	3.25	1.93	0.70e-02
30.00	18.00	0.450	1.67	0.60e-02	3.28	2.11	0.76e-02
30.00	24.00	0.450	1.67	0.60e-02	3.23	1.82	0.65e-02
30.00	30.00	0.400	1.48	0.53e-02	3.12	1.27	0.46e-02

LDA - Average velocity = 1.90 m/s, Total flow rate = 0.247 m^3/s

HWA - Average velocity = 1.75 m/s, Total flow rate = 0.226 m^3/s

Table 4: LDA and HWA Data for Ventilator #4, Condition B
-Page C.5-

*** FLOW RESULTS FOR hood#15i ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.900e-01	0.33	0.10e-02	2.73	0.22	0.68e-03
0.00	5.50	0.800e-01	0.30	0.90e-03	2.71	0.20	0.60e-03
0.00	11.00	0.130	0.48	0.15e-02	2.73	0.22	0.68e-03
0.00	16.50	0.120	0.44	0.12e-02	2.75	0.25	0.71e-03
0.00	21.20	0.100	0.37	0.96e-03	2.72	0.21	0.55e-03
5.50	0.00	0.800e-01	0.30	0.90e-03	2.77	0.28	0.85e-03
5.50	5.50	0.900e-01	0.33	0.10e-02	2.73	0.22	0.68e-03
5.50	11.00	0.130	0.48	0.15e-02	2.71	0.20	0.60e-03
5.50	16.50	0.120	0.44	0.12e-02	2.71	0.20	0.56e-03
5.50	21.20	0.100	0.37	0.96e-03	2.74	0.24	0.62e-03
11.00	0.00	0.800e-01	0.30	0.90e-03	2.76	0.27	0.81e-03
11.00	5.50	0.800e-01	0.30	0.90e-03	2.74	0.24	0.72e-03
11.00	11.00	0.120	0.44	0.13e-02	2.72	0.21	0.64e-03
11.00	16.50	0.120	0.44	0.12e-02	2.70	0.19	0.52e-03
11.00	21.20	0.900e-01	0.33	0.86e-03	2.70	0.19	0.48e-03
16.50	0.00	0.800e-01	0.30	0.83e-03	2.74	0.24	0.67e-03
16.50	5.50	0.900e-01	0.33	0.93e-03	2.74	0.24	0.67e-03
16.50	11.00	0.120	0.44	0.12e-02	2.75	0.25	0.71e-03
16.50	16.50	0.130	0.48	0.13e-02	2.73	0.22	0.58e-03
16.50	21.20	0.800e-01	0.30	0.71e-03	2.74	0.24	0.57e-03
21.20	0.00	0.900e-01	0.33	0.86e-03	2.76	0.27	0.69e-03
21.20	5.50	0.900e-01	0.33	0.86e-03	2.75	0.25	0.65e-03
21.20	11.00	0.120	0.44	0.11e-02	2.74	0.24	0.62e-03
21.20	16.50	0.120	0.44	0.11e-02	2.75	0.25	0.60e-03
21.20	21.20	0.800e-01	0.30	0.65e-03	2.74	0.24	0.53e-03

LDA - Average velocity = 0.36 m/s, Total flow rate = 0.026 m^3/s

HWA - Average velocity = 0.22 m/s, Total flow rate = 0.016 m^3/s

Table 5: LDA and HWA Data for Fume Hood #15, Portal (i)
-Page C.6-

*** FLOW RESULTS FOR hood#15ii ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.800e-01	0.30	0.90e-03	2.76	0.27	0.81e-03
0.00	5.50	0.100	0.37	0.11e-02	2.74	0.24	0.72e-03
0.00	11.00	0.120	0.44	0.13e-02	2.75	0.25	0.76e-03
0.00	16.50	0.120	0.44	0.12e-02	2.71	0.20	0.56e-03
0.00	21.20	0.100	0.37	0.96e-03	2.70	0.19	0 48e-03
5.50	0.00	0.900e-01	0.33	0.10e-02	2.75	0.25	0.76e-03
5.50	5.50	0.100	0.37	0.11e-02	2.73	0.22	0.68e-03
5.50	11.00	0.120	0.44	0.13e-02	2.70	0.19	0.56e-03
5.50	16.50	0.130	0.48	0.13e-02	2.72	0.21	0.59e-03
5.50	21.20	0.900e-01	0.33	0.86e-03	2.70	0.19	0.48e-03
11.00	0.00	0.100	0.37	0.11e-02	2.73	0.22	0.68e-03
11.00	5.50	0.110	0.41	0.12e-02	2.75	0.25	0.76e-03
11.00	11.00	0.110	0.41	0.12e-02	2.73	0.22	0.68e-03
11.00	16.50	0.120	0.44	0.12e-02	2.74	0.24	0.67e-03
11.00	21.20	0.900e-01	0.33	0.86e-03	2.72	0.21	0.55e-03
16.50	0.00	0.100	0.37	0.10e-02	2.76	0.27	0.75e-03
16.50	5.50	0.100	0.37	0.10e-02	2.73	0.22	0.63e-03
16.50	11.00	0.900e-01	0.33	0.93e-03	2.73	0.22	0.63e-03
16.50	16.50	0.130	0.48	0.13e-02	2.72	0.21	0.55e-03
16.50	21.20	0.110	0.41	0.98e-03	2.71	0.20	0.48e-03
21.20	0.00	0.110	0.41	0.11e-02	2.72	0.21	0.55e-03
21.20	5.50	0.110	0.41	0.11e-02	2.73	0.22	0.58e-03
21.20	11.00	0.800e-01	0.30	0.77e-03	2.74	0.24	0.62e-03
21.20	16.50	0.130	0.48	0.12e-02	2.73	0.22	0.54e-03
21.20	21.20	0.100	0.37	0.82e-03	2.74	0.24	0.53e-03

LDA - Average velocity = 0.37 m/s, Total flow rate = 0.027 m^3/s

HWA - Average velocity = 0.22 m/s, Total flow rate = 0.016 m^3/s

Table 6: LDA and HWA Data for Fume Hood #15, Portal (ii)
-Page C.7-

*** FLOW RESULTS FOR hood#15iii ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.100	0.37	0.11e-02	2.75	0.25	0.76e-03
0.00	5.50	0.800e-01	0.30	0.90e-03	2.75	0.25	0.76e-03
0.00	11.00	0.900e-01	0.33	0.10e-02	2.76	0.27	0.81e-03
0.00	16.50	0.130	0.48	0.13e-02	2.72	0.21	0.59e-03
0.00	21.20	0.110	0.41	0.11e-02	2.72	0.21	0.55e-03
5.50	0.00	0.110	0.41	0.12e-02	2.77	0.28	0.85e-
5.50	5.50	0.800e-01	0.30	0.90e-03	2.76	0.27	0.81e-
5.50	11.00	0.100	0.37	0.11e-02	2.75	0.25	0.76e-03
5.50	16.50	0.130	0.48	0.13e-02	2.74	0.24	0.67e-03
5.50	21.20	0.120	0.44	0.11e-02	2.75	0.25	0.65e-03
11.00	0.00	0.120	0.44	0.13e-02	2.75	0.25	0.76e-03
11.00	5.50	0.800e-01	0.30	0.90e-03	2.77	0.28	0.85e-03
11.00	11.00	0.900e-01	0.33	0.10e-02	2.75	0.25	0.76e-03
11.00	16.50	0.140	0.52	0.15e-02	2.71	0.20	0.56e-03
11.00	21.20	0.120	0.44	0.11e-02	2.70	0.19	0.48e-03
16.50	0.00	0.110	0.41	0.11e-02	2.76	0.27	0.75e-03
16.50	5.50	0.900e-01	0.33	0.93e-03	2.80	0.33	0.93e-03
16.50	11.00	0.800e-01	0.30	0.83e-03	2.76	0.27	0.75e-03
16.50	16.50	0.140	0.52	0.13e-02	2.75	0.25	0.66e-03
16.50	21.20	0.120	0.44	0.11e-02	2.74	0.24	0.57e-03
21.20	0.00	0.110	0.41	0.11e-02	2.75	0.25	0.65e-03
21.20	5.50	0.800e-01	0.30	0.77e-03	2.73	0.22	0.58e-03
21.20	11.00	0.800e-01	0.30	0.77e-03	2.72	0.21	0.55e-03
21.20	16.50	0.130	0.48	0.12e-02	2.74	0.24	0.57e-03
21.20	21.20	0.120	0.44	0.98e-03	2.71	0.20	0.44e-03

LDA - Average velocity = 0.37 m/s, Total flow rate = 0.027 m^3/s

HWA - Average velocity = 0.24 m/s, Total flow rate = 0.017 m^3/s

Table 7: LDA and HWA Data for Fume Hood #15, Portal (iii)
-Page C.8-

*** FLOW RESULTS FOR hood#14 ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.30	0.120	0.44	0.11e-01	2.78	0.30	0.72e-02
0.00	7.00	0.110	0.41	0.10e-01	2.82	0.37	0.91e-02
0.00	14.00	0.900e-01	0.33	0.84e-02	2.85	0.43	0.11e-01
0.00	21.00	0.800e-01	0.30	0.75e-02	2.84	0.41	0.10e-01
0.00	28.00	0.800e-01	0.30	0.94e-02	2.83	0.39	0.12e-01
0.00	38.70	0.100	0.37	0.14e-01	2.80	0.33	0.13e-01
36.00	0.30	0.100	0.37	0.89e-02	2.88	0.49	0.12e-01
36.00	7.00	0.900e-01	0.33	0.82e-02	2.85	0.43	0.11e-01
36.00	14.00	0.100	0.37	0.93e-02	2.88	0.49	0.12e-01
36.00	21.00	0.110	0.41	0.10e-01	2.90	0.54	0.14e-01
36.00	28.00	0.110	0.41	0.13e-01	2.88	0.49	0.16e-01
36.00	38.70	0.130	0.48	0.19e-01	2.84	0.41	0.16e-01
72.00	0.30	0.120	0.44	0.11e-01	2.86	0.45	0.11e-01
72.00	7.00	0.120	0.44	0.11e-01	2.85	0.43	0.11e-01
72.00	14.00	0.100	0.37	0.93e-02	2.88	0.49	0.12e-01
72.00	21.00	0.100	0.37	0.93e-02	2.88	0.49	0.12e-01
72.00	28.00	0.130	0.48	0.15e-01	2.87	0.47	0.15e-01
72.00	38.70	0.150	0.56	0.21e-01	2.82	0.37	0.14e-01
108.00	0.30	0.140	0.52	0.12e-01	2.91	0.56	0.14e-01
108.00	7.00	0.130	0.48	0.12e-01	2.92	0.59	0.15e-01
108.00	14.00	0.130	0.48	0.12e-01	2.92	0.59	0.15e-01
108.00	21.00	0.150	0.56	0.14e-01	2.91	0.56	0.14e-01
108.00	28.00	0.140	0.52	0.17e-01	2.91	0.56	0.18e-01
108.00	38.70	0.180	0.67	0.26e-01	2.84	0.41	0.16e-01
144.00	0.30	0.150	0.56	0.13e-01	2.92	0.59	0.14e-01
144.00	7.00	0.170	0.63	0.16e-01	2.94	0.64	0.16e-01
144.00	14.00	0.130	0.48	0.12e-01	2.92	0.59	0.15e-01
144.00	21.00	0.180	0.67	0.17e-01	2.94	0.64	0.16e-01
144.00	28.00	0.170	0.63	0.20e-01	2.90	0.54	0.17e-01
144.00	38.70	0.140	0.52	0.20e-01	2.85	0.43	0.16e-01
180.00	0.30	0.130	0.48	0.12e-01	2.91	0.56	0.14e-01
180.00	7.00	0.150	0.56	0.14e-01	2.95	0.67	0.17e-01
180.00	14.00	0.120	0.44	0.11e-01	2.93	0.62	0.16e-01
180.00	21.00	0.120	0.44	0.11e-01	2.94	0.64	0.16e-01
180.00	28.00	0.100	0.37	0.12e-01	2.88	0.49	0.16e-01
180.00	38.70	0.100	0.37	0.14e-01	2.84	0.41	0.16e-01

LDA - Average velocity = 2.48 m/s, Total flow rate = 0.470 m^3/s

HWA - Average velocity = 2.62 m/s, Total flow rate = 0.497 m^3/s

Table 8: LDA and HWA Data for Fume Hood #14
-Page C.9-

*** FLOW RESULTS FOR hood#10 ***

x [cm]	y [cm]	LDA [MHz]	LDA [m/s]	LDA [m^3/s]	HWA [Volts]	HWA [m/s]	HWA [m^3/s]
0.00	0.00	0.140	0.52	0.97e-02	2.81	0.35	0.66e-02
0.00	7.50	0.150	0.56	0.10e-01	2.88	0.49	0.92e-02
0.00	15.00	0.140	0.52	0.97e-02	2.90	0.54	0.10e-01
0.00	22.50	0.110	0.41	0.76e-02	2.89	0.52	0.97e-02
0.00	30.00	0.110	0.41	0.81e-02	2.86	0.45	0.89e-02
0.00	38.40	0.130	0.48	0.10e-01	2.84	0.41	0.86e-02
25.00	0.00	0.120	0.44	0.83e-02	2.82	0.37	0.69e-02
25.00	7.50	0.180	0.67	0.12e-01	2.88	0.49	0.92e-02
25.00	15.00	0.150	0.56	0.10e-01	2.88	0.49	0.92e-02
25.00	22.50	0.150	0.56	0.10e-01	2.92	0.59	0.11e-01
25.00	30.00	0.150	0.56	0.11e-01	2.92	0.59	0.12e-01
25.00	38.40	0.140	0.52	0.11e-01	2.89	0.52	0.11e-01
50.00	0.00	0.150	0.56	0.10e-01	2.87	0.47	0.88e-02
50.00	7.50	0.190	0.70	0.13e-01	2.88	0.49	0.92e-02
50.00	15.00	0.190	0.70	0.13e-01	2.91	0.56	0.11e-01
50.00	22.50	0.190	0.70	0.13e-01	2.92	0.59	0.11e-01
50.00	30.00	0.170	0.63	0.13e-01	2.91	0.56	0.11e-01
50.00	38.40	0.140	0.52	0.11e-01	2.87	0.47	0.99e-02
75.00	0.00	0.160	0.59	0.11e-01	2.92	0.59	0.11e-01
75.00	7.50	0.190	0.70	0.13e-01	2.94	0.64	0.12e-01
75.00	15.00	0.180	0.67	0.12e-01	2.94	0.64	0.12e-01
75.00	22.50	0.220	0.81	0.15e-01	2.96	0.70	0.13e-01
75.00	30.00	0.190	0.70	0.14e-01	2.95	0.67	0.13e-01
75.00	38.40	0.140	0.52	0.11e-01	2.91	0.56	0.12e-01
100.00	0.00	0.140	0.52	0.97e-02	2.94	0.64	0.12e-01
100.00	7.50	0.190	0.70	0.13e-01	2.96	0.70	0.13e-01
100.00	15.00	0.170	0.63	0.12e-01	2.96	0.70	0.13e-01
100.00	22.50	0.200	0.74	0.14e-01	2.94	0.64	0.12e-01
100.00	30.00	0.180	0.67	0.13e-01	2.94	0.64	0.13e-01
100.00	38.40	0.140	0.52	0.11e-01	2.89	0.52	0.11e-01
125.00	0.00	0.160	0.59	0.11e-01	2.89	0.52	0.97e-02
125.00	7.50	0.170	0.63	0.12e-01	2.92	0.59	0.11e-01
125.00	15.00	0.170	0.63	0.12e-01	2.90	0.54	0.10e-01
125.00	22.50	0.140	0.52	0.97e-02	2.89	0.52	0.97e-02
125.00	30.00	0.150	0.56	0.11e-01	2.89	0.52	0.10e-01
125.00	38.40	0.160	0.59	0.12e-01	2.83	0.39	0.81e-02

LDA - Average velocity = 1.97 m/s, Total flow rate = 0.410 m^3/s

HWA - Average velocity = 1.82 m/s, Total flow rate = 0.379 m^3/s

Table 9: LDA and HWA Data for Fume Hood #10
-Page C.10-

TRACER GAS STUDY IN THE OHRD TRITIUM LABORATORY (ALL DISTANCE MEASUREMENT IN FEET AND ALL SF6 CONC. IN PPM)

height	1				5				10			
distance E wall	2	14	24	36	2	14	24	36	2	14	24	36
N wall												
6	1.45	1.45	1.43	1.27	1.4	1.53	2.07	1.42	1.15	1.73	2.4	1.97
16.5	1.45	1.26	2.6	1.66	1.43	1.92	3.52	1.86	1.8	1.51	5.2	1.97
27	1.23	1.7	1.51	9.6	1.25	1.66	1.97	5.72	1.33	1.66	2.13	2.6
39	1.12	1.55	1.62	3.38	1.12	1.7	1.62	3.52	1.2	1.7	1.66	2.22
51.5	1.1	1.39	2.6	3.33	1.2	1.66	2.03	3.23	1.15	1.66	1.97	2.22
6	0.4	0.33	0.53	0.54	0.33	0.36	0.43	0.44	0.27	0.5	0.42	0.405
16.5	0.42	0.42	0.43	0.39	0.44	0.44	0.53	0.41	0.42	0.6	0.57	0.53
27	0.53	0.4	0.4	0.74	0.54	0.42	0.54	0.72	0.52	0.53	0.74	2.6
39	0.55	0.54	0.39	0.59	0.56	0.6	0.6	2.25	0.58	0.75	0.75	1.85
51.5	0.63	0.26	0.33	0.57	0.61	0.28	0.52	1	0.69	0.47	0.53	0.95

Table 10: Gas Concentration Survey

-Page C.11-

APPENDIX D
MANUAL FOR PC PROGRAM
FOR FLOW RATE DETERMINATION

MANUAL for PROGRAM DUCTFLOW

INTRODUCTION

Program Ductflow was written by Kings Engineering Associates in a standard FORTRAN which is compatible with almost any FORTRAN compiler. In particular, it is known to pass without error through PC compatible compilers.

Program Ductflow is a simple program which accepts data from either Laser Doppler Anemometer (LDA) or Hot Wire Anemometer (HWA) measurement systems. If a hot wire system is being used, the program user must edit Program Ductflow in order to implant the calibration equation which corresponds to the particular hot wire being used. This program assumes that the LDA system being used is fully automated and has as its output the desired velocity values. The data analysis includes calculation of the grid position velocities and flow rates, the average velocity in the duct opening and the total flow rate. The results are then output in tables which will include the results from HWA, LDA or BOTH as has been requested by the user.

This manual will outline the calculation methods used and the input data required by Program Ductflow. Suggestions concerning the number of grid points required for a given application will also be given. Some examples of the program input and resulting output are provided to clarify the program requirements and abilities.

CALCULATION METHODS

LDA Theory

The calculation of velocity values from LDA system output is based entirely on the theoretically derived linear relationship between the frequency of the doppler bursts, as out-

put by a suitable frequency tracker, and the in-plane flow velocity. This relationship for velocity, U, in [m/s] is given in the following equation:

$$U = \frac{f\lambda}{2\sin(\frac{\phi\pi}{180})} \tag{1}$$

where, f is the doppler frequency in [MHz], λ is the wavelength of the laser beam in [m], and ϕ is one-half of the beam convergence angle in [degrees]. The values of ϕ and possibly λ will vary with the LDA system being used. LDA systems which incorporate the calculation of the velocity as described in equation (1) are now available. Program Ductflow assumes that previously calculated velocities will be input.

HWA Theory

Unlike the LDA system, a HWA system must be calibrated before the voltage readings can be interpreted. Each hot wire will have a different calibration curve which must be editted into Program Ductflow by the user. The proper calibration equation for relating the output reading in [Volts] to the velocity in [m/s] must be placed at the well-marked position within Program Ductflow.

Flow Rate and Average Velocity Calculations

The total flow rate is calculated as the sum of the flow rates through rectangular grid sections as defined by the user grid positions. Each individual flow rate is the product of the measured velocity multiplied by a normal area. It is assumed that the velocity measurements have been taken in a plane which is perpendicular to the face of the duct opening. The rectangular area at each grid position (i, j) is determined by dividing in half the area defined by the grid positions (i-1, j-1),(i-1, j+1),(i+1, j+1),and (i+1, j-1). This method of calculation requires that all points of measurement form a rectangular grid. It is not necessary for all grid positions to be equidistant. Obviously, the area surrounding the outer grid points cannot be

measured in this way since some of the coordinates as they are given above would not be defined. At the edges it was therefore necessary to define the area in a different fashion. When i equals 1 the area is defined as the distance between position (1, j) and (2, j) multiplied by one-half the distance between positions (1, j+1) and (1, j-1). Similar calculations are made on each edge of the grid.

The average velocity is defined as the total flow rate divided by the total flow area. The total flow area is defined as the sum of all the areas used to determine the individual flow rates. It should be noted that this area will be slightly larger than the original measurement grid since the edge velocities have been averaged over areas which extend beyond the grid positions.

REQUIRED INPUT DATA

Program Ductflow requires some initial input through interactive statements with the user and then a file containing the grid positions and data readings is also read. Each of the interactive input requests is given below with an explanation of the required input.

1. Input an identifier for the duct (max. length=11) :

This identifier will be placed at the top of the results table so that each table is suitably titled.

2. Input the number of grid points in each of the x and y directions:

The values should be input as integers separated by a comma.

3. Do you have LDA, HWA or BOTH types of measurements?

This program will produce results for both or only one of the measurement techniques if the user identifies the incoming data as LDA, HWA or BOTH.

4. Input the filename for the datafile which contains the x and y positions [cm] and the readings (LDA [m/s] and/or HWA [Volts]):

This datafile must be prepared in advance by the user. The filename for the datafile must be no longer than 11 characters.

The Datafile

The datafile is simply a list of the data positions and the readings from the LDA and/or HWA. If both LDA and HWA are used they should be listed with the LDA values given first. For each measurement position the x position, y position, LDA values (if available) and HWA values (if available) should be input on a single line with commas between the data values. The total length of the datafile should be equal to the total number of grid positions.

GRID SELECTION

The choice of appropriate measurement positions will be highly site dependent. The number of grid points in the x and y directions as well as the grid spacings must be determined by those taking the measurements. Although the final grid selection must be made at the site, the following guidelines may in useful as a starting point in the development of a suitable grid pattern.

1. The number of grid positions will not increase linearly with the size of the duct opening. Any duct opening will have velocities which range from relatively high velocities near the centre of the duct to negligible velocities at the edges of the duct. A larger opening will disperse, over a larger distance, the same velocity gradient found in the smaller duct. Therefore, it is possible to measure a very large opening with only a few more measurements than one would use on an opening of half its size.

2. An improved accuracy may result by increasing the grid density at the edges of the duct opening where the largest velocity gradients are likely to occur. This would entail perhaps a single extra grid line. A large number of added lines would not significantly improve the measured flow rate since the flow rates at the edges tend to be lower than those found in the centre of the duct and therefore some inaccuracy will not noticeably alter the final result.

3. Ducts such as ventilators and fumehoods tend to have slowly varying flow fields. This fact reduces the number of required measurement positions. For example, 36 grid points over an area of 40 cm by 40 cm. would, in all likelihood, result in a grid independent total flow rate.

4. Program Ductflow requires a rectangular grid but this does not mean that the grid should be square. In fact, in the case of a long shallow duct opening such as a partially closed fume-hood, the number of grid lines in the x and y directions will be similar since the velocity gradients in the vertical direction will probably be much greater than those in the horizontal direction.

5. The grid must be in the plane of the duct opening so that the velocity measurements are made perpendicular to the grid. The grid should be placed as close as possible to the duct opening. If one is not able to take the velocity measurements directly in the duct opening, then one must increase the grid to go beyond the edges of the opening.

EXAMPLE DATA AND RESULTS

Three examples of possible input and output have been appended to this report. The firest two examples have only one measurement technique being used while the third includes data from both HWA and LDA readings. The results are presented as they would be output from Program Ductflow. Velocities and flow rates are given for each measurement position and then the average velocity and the total flow rate are given beneath the columns of individual results.

EXAMPLE #1

Interactive Input

```
vent-9
6,6
LDA
V9.dat
```

Datafile

```
0.0,0.0,1.04
0.0,6.0,1.00
0.0,12.,1.33
0.0,18.,1.63
0.0,24.,1.41
0.0,30.,1.00
6.0,0.0,1.00
6.0,6.0,1.55
6.0,12.,2.22
6.0,18.,2.52
6.0,24.,2.15
6.0,30.,1.30
12.,0.0,1.04
12.,6.0,2.22
12.,12.,2.55
12.,18.,2.92
12.,24.,2.41
12.,30.,1.26
18.,0.0,1.11
18.,6.0,2.04
18.,12.,2.55
18.,18.,2.78
18.,24.,2.41
18.,30.,1.26
24.,0.0,0.93
24.,6.0,1.48
24.,12.,1.85
24.,18.,2.26
24.,24.,1.78
24.,30.,1.07
30.,0.0,0.96
30.,6.0,1.04
30.,12.,1.11
30.,18.,1.26
30.,24.,1.07
30.,30.,1.07
```

EXAMPLE #2

Interactive Input

```
hood-10
6,6
HWA
H10.dat
```

Datafile

```
0.0,0.0,2.81
0.0,7.5,2.88
0.0,15.,2.90
0.0,22.5,2.89
0.0,30.,2.86
0.0,38.4,2.84
25.,0.0,2.82
25.,7.5,2.88
25.,15.,2.88
25.,22.5,2.92
25.,30.,2.92
25.,38.4,2.89
50.,0.0,2.87
50.,7.5,2.88
50.,15.,2.91
50.,22.5,2.92
50.,30.,2.91
50.,38.4,2.87
75.,0.0,2.92
75.,7.5,2.94
75.,15.,2.94
75.,22.5,2.96
75.,30.,2.95
75.,38.4,2.91
100.,0.0,2.94
100.,7.5,2.96
100.,15.,2.96
100.,22.5,2.94
100.,30.,2.94
100.,38.4,2.89
125.,0.0,2.89
125.,7.5,2.92
125.,15.,2.90
125.,22.5,2.89
125.,30.,2.89
125.,38.4,2.83
```

EXAMPLE #3

Interactive Input

```
hood-14
6,6
BOTH
H14.dat
```

Datafile

```
0.0,0.3,.44,2.78
0.0,7.0,.41,2.82
0.0,14.,.33,2.85
0.0,21.,.30,2.84
0.0,28.,.30,2.83
0.0,38.7,.37,2.80
36.,0.3,.37,2.88
36.,7.0,.33,2.85
36.,14.,.37,2.88
36.,21.,.41,2.90
36.,28.,.41,2.88
36.,38.7,.48,2.84
72.,0.3,.44,2.86
72.,7.0,.44,2.85
72.,14.,.37,2.88
72.,21.,.37,2.88
72.,28.,.48,2.87
72.,38.7,.56,2.82
108.,0.3,.52,2.91
108.,7.0,.48,2.92
108.,14.,.48,2.92
108.,21.,.56,2.91
108.,28.,.52,2.91
108.,38.7,.67,2.84
144.,0.3,.56,2.92
144.,7.0,.63,2.94
144.,14.,.48,2.92
144.,21.,.67,2.94
144.,28.,.63,2.90
144.,38.7,.52,2.85
180.,0.3,.48,2.91
180.,7.0,.56,2.95
180.,14.,.44,2.93
180.,21.,.44,2.94
180.,28.,.37,2.88
180.,38.7,.37,2.84
```

EXAMPLE #1

FLOW RESULTS FOR vent-9

x [cm]	y [cm]	LDA [m/s]	LDA [m3/s]
0.00	0.00	1.04	0.37e-02
0.00	6.00	1.00	0.36e-02
0.00	12.00	1.33	0.48e-02
0.00	18.00	1.63	0.59e-02
0.00	24.00	1.41	0.51e-02
0.00	30.00	1.00	0.36e-02
6.00	0.00	1.00	0.36e-02
6.00	6.00	1.55	0.56e-02
6.00	12.00	2.22	0.80e-02
6.00	18.00	2.52	0.91e-02
6.00	24.00	2.15	0.77e-02
6.00	30.00	1.30	0.47e-02
12.00	0.00	1.04	0.37e-02
12.00	6.00	2.22	0.80e-02
12.00	12.00	2.55	0.92e-02
12.00	18.00	2.92	0.11e-01
12.00	24.00	2.41	0.87e-02
12.00	30.00	1.26	0.45e-02
18.00	0.00	1.11	0.40e-02
18.00	6.00	2.04	0.73e-02
18.00	12.00	2.55	0.92e-02
18.00	18.00	2.78	0.10e-01
18.00	24.00	2.41	0.87e-02
18.00	30.00	1.26	0.45e-02
24.00	0.00	0.93	0.33e-02
24.00	6.00	1.48	0.53e-02
24.00	12.00	1.85	0.67e-02
24.00	18.00	2.26	0.81e-02
24.00	24.00	1.78	0.64e-02
24.00	30.00	1.07	0.39e-02
30.00	0.00	0.96	0.35e-02
30.00	6.00	1.04	0.37e-02
30.00	12.00	1.11	0.40e-02
30.00	18.00	1.26	0.45e-02
30.00	24.00	1.07	0.39e-02
30.00	30.00	1.07	0.39e-02

LDA - Average velocity = 1.63 m/s
Total flow rate = 0.211 m3/s

EXAMPLE #2

FLOW RESULTS FOR hood-10

x [cm]	y [cm]	HWA [Volt]	HWA [m/s]	HWA [m3/s]
0.00	0.00	2.81	0.35	0.66e-02
0.00	7.50	2.88	0.49	0.92e-02
0.00	15.00	2.90	0.54	0.10e-01
0.00	22.50	2.89	0.52	0.97e-02
0.00	30.00	2.86	0.45	0.89e-02
0.00	38.40	2.84	0.41	0.86e-02
25.00	0.00	2.82	0.37	0.69e-02
25.00	7.50	2.88	0.49	0.92e-02
25.00	15.00	2.88	0.49	0.92e-02
25.00	22.50	2.92	0.59	0.11e-01
25.00	30.00	2.92	0.59	0.12e-01
25.00	38.40	2.89	0.52	0.11e-01
50.00	0.00	2.87	0.47	0.88e-02
50.00	7.50	2.88	0.49	0.92e-02
50.00	15.00	2.91	0.56	0.11e-01
50.00	22.50	2.92	0.59	0.11e-01
50.00	30.00	2.91	0.56	0.11e-01
50.00	38.40	2.87	0.47	0.99e-02
75.00	0.00	2.92	0.59	0.11e-01
75.00	7.50	2.94	0.64	0.12e-01
75.00	15.00	2.94	0.64	0.12e-01
75.00	22.50	2.96	0.70	0.13e-01
75.00	30.00	2.95	0.67	0.13e-01
75.00	38.40	2.91	0.56	0.12e-01
100.00	0.00	2.94	0.64	0.12e-01
100.00	7.50	2.96	0.70	0.13e-01
100.00	15.00	2.96	0.70	0.13e-01
100.00	22.50	2.94	0.64	0.12e-01
100.00	30.00	2.94	0.64	0.13e-01
100.00	38.40	2.89	0.52	0.11e-01
125.00	0.00	2.89	0.52	0.97e-02
125.00	7.50	2.92	0.59	0.11e-01
125.00	15.00	2.90	0.54	0.10e-01
125.00	22.50	2.89	0.52	0.97e-02
125.00	30.00	2.89	0.52	0.10e-01
125.00	38.40	2.83	0.39	0.81e-02

HWA - Average velocity = 1.82 m/s
Total flow rate = 0.379 m^3/s

EXAMPLE #3

FLOW RESULTS FOR hood-14

x [cm]	y [cm]	LDA [m/s]	LDA [m3/s]	HWA [Volt]	HWA [m/s]	HWA [m3/s]
0.00	0.30	0.44	0.11e-01	2.78	0.30	0.72e-02
0.00	7.00	0.41	0.10e-01	2.82	0.37	0.91e-02
0.00	14.00	0.33	0.83e-02	2.85	0.43	0.11e-01
0.00	21.00	0.30	0.76e-02	2.84	0.41	0.10e-01
0.00	28.00	0.30	0.96e-02	2.83	0.39	0.12e-01
0.00	38.70	0.37	0.14e-01	2.80	0.33	0.13e-01
36.00	0.30	0.37	0.89e-02	2.88	0.49	0.12e-01
36.00	7.00	0.33	0.81e-02	2.85	0.43	0.11e-01
36.00	14.00	0.37	0.93e-02	2.88	0.49	0.12e-01
36.00	21.00	0.41	0.10e-01	2.90	0.54	0.14e-01
36.00	28.00	0.41	0.13e-01	2.88	0.49	0.16e-01
36.00	38.70	0.48	0.18e-01	2.84	0.41	0.16e-01
72.00	0.30	0.44	0.11e-01	2.86	0.45	0.11e-01
72.00	7.00	0.44	0.11e-01	2.85	0.43	0.11e-01
72.00	14.00	0.37	0.93e-02	2.88	0.49	0.12e-01
72.00	21.00	0.37	0.93e-02	2.88	0.49	0.12e-01
72.00	28.00	0.48	[illegible]15e-01	2.87	0.47	0.15e-01
72.00	38.70	0.56	[illegible]22e-01	2.82	0.37	0.14e-01
108.00	0.30	0.52	0.13e-01	2.91	0.56	0.14e-01
108.00	7.00	0.48	0.12e-01	2.92	0.59	0.15e-01
108.00	14.00	0.48	0.12e-01	2.92	0.59	0.15e-01
108.00	21.00	0.56	0.14e-01	2.91	0.56	0.14e-01
108.00	28.00	0.52	0.17e-01	2.91	0.56	0.18e-01
108.00	38.70	0.67	0.26e-01	2.84	0.41	0.16e-01
144.00	0.30	0.56	0.14e-01	2.92	0.59	0.14e-01
144.00	7.00	0.63	0.16e-01	2.94	0.64	0.16e-01
144.00	14.00	0.48	0.12e-01	2.92	0.59	0.15e-01
144.00	21.00	0.67	0.17e-01	2.94	0.64	0.16e-01
144.00	28.00	0.63	0.20e-01	2.90	0.54	0.17e-01
144.00	38.70	0.52	0.20e-01	2.85	0.43	0.16e-01
180.00	0.30	0.48	0.12e-01	2.91	0.56	0.14e-01
180.00	7.00	0.56	0.14e-01	2.95	0.67	0.17e-01
180.00	14.00	0.44	0.11e-01	2.93	0.62	0.16e-01
180.00	21.00	0.44	0.11e-01	2.94	0.64	0.16e-01
180.00	28.00	0.37	0.12e-01	2.88	0.49	0.16e-01
180.00	38.70	0.37	0.14e-01	2.84	0.41	0.16e-01

LDA - Average velocity = 2.48 m/s
Total flow rate = 0.470 m3/s

HWA - Average velocity = 2.62 m/s
Total flow rate = 0.497 m3/s

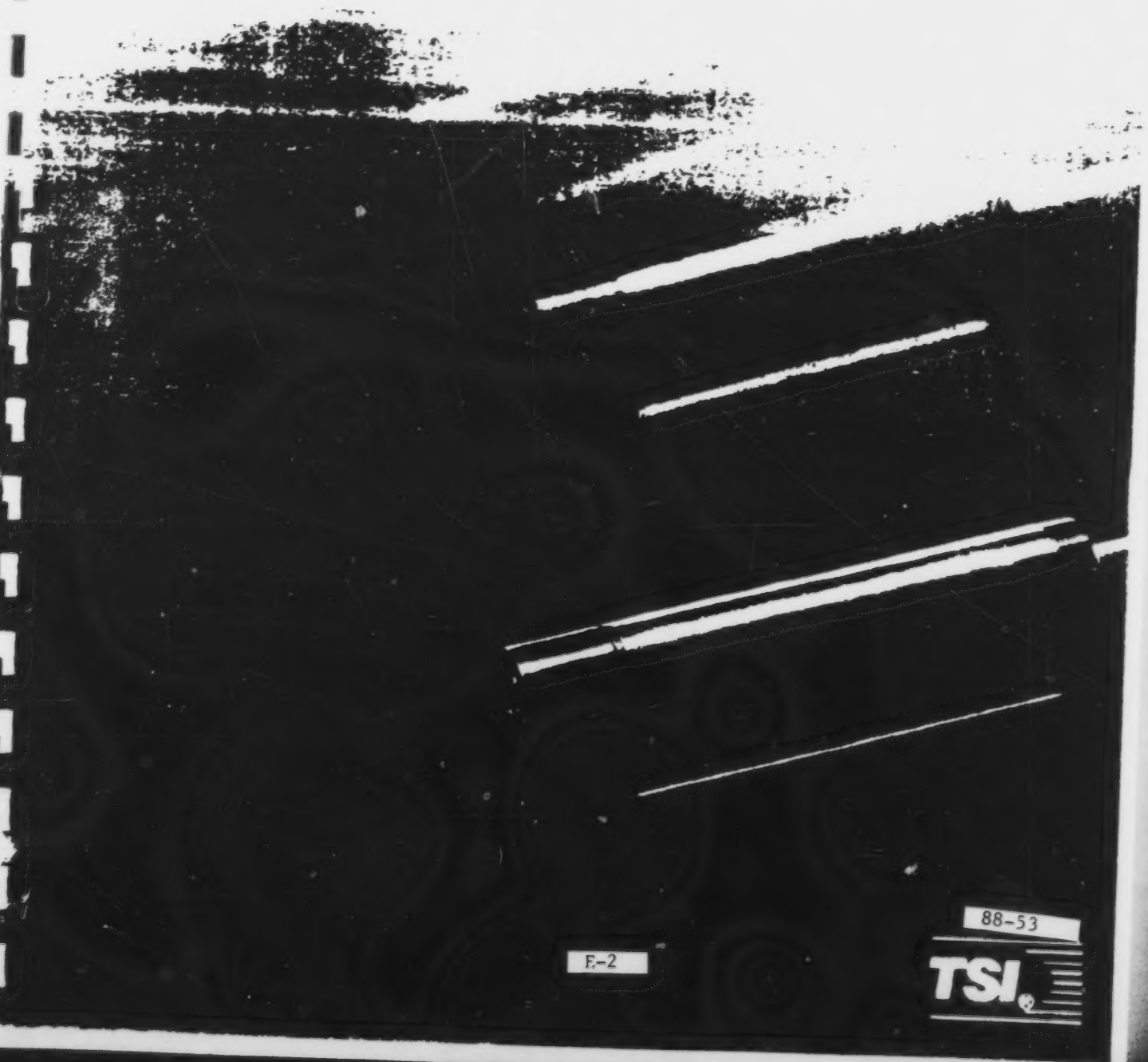
```
      program ductflow
      character*4 vtype
      character*11 titre,title
      real x(100,100),y(100,100),volt(100,100)
      real vlda(100,100),vhwa(100,100),qlda(100,100),qhwa(100,100)
      real xsize(100,100),ysize(100,100)
      real qldatot,qhwatot,vldaavg,vhwaavg,xtot,ytot
      integer nx,ny
c
      write (*,100)
  100 format ('1',  //
     +'  ***************************************************************'/
     +'  **                                                           **'/
     +'  **                          DUCTFLOW                         **'/
     +'  **                                                           **'/
     +'  **          - Written  Nov. /87                              **'/
     +'  **          - by Kings Engineering Associates Ltd            **'/
     +'  **                                                           **'/
     +'  ***************************************************************'//
     +/'  This program has be written to process data as generated by'/
     +'  HWA and LDA in the field to provide information on the '/
     +'  velocity distribution, average velocity and volume flow rate.'/
     +/'  NOTE: '/
     +'   There is a programming line which is HWA system dependent.'/
     +'   This line has been flagged within this FORTRAN program for'/
     +'   easy identification.'////)
c
      write (*,110)
  110 format ('$ Input an identifier for the duct (max. length=11): ')
      read (*,' (a11) ') titre
      write (*,120)
  120 format ('$ Input the number of grid points in each of the x and y
     +directions: ')
      read (*,*) nx,ny
      write (*,130)
  130 format ('$ Do you have LDA, HWA or BOTH types of measurements? ')
      read (*,' (a4) ') vtype
      write (*,140)
  140 format ('$ Input the filename for the datafile which contains the
     +x and y positions [cm] and the readings (LDA [m/s] and/or HWA [Vol
     +ts] : ')
      read (*,' (a11) ') title
c
      open (unit=1,file=title,status='old')
      do 10  i=1,nx
         do 20  j=1,ny
            if (vtype .eq. 'LDA ') read (1,*) x(i,j),y(i,j),vlda(i,j)
            if (vtype .eq. 'HWA ') read (1,*) x(i,j),y(i,j),volt(i,j)
            if (vtype .eq. 'BOTH') read (1,*) x(i,j),y(i,j),vlda(i,j),
     +                                                      volt(i,j)
   20       continue
   10    continue
      close (unit=1)
c
      open (unit=1,file=titre,status='new')
      write (1,150) titre
  150 format (///'                FLOW RESULTS FOR ',a11//)
      if (vtype.eq.'LDA ') write (1,160) 'x [cm]','y [cm]'
     +                                   ,'LDA [m/s]','LDA [m3/s]'
      if (vtype.eq.'HWA ') write (1,162) 'x [cm]','y [cm]','HWA [Volt]'
     +                                   ,'HWA [m/s]','HWA [m3/s]'
      if (vtype.eq.'BOTH') write (1,160) 'x [cm]','y [cm]','LDA [m/s]'
     +             ,'LDA [m3/s]','HWA [Volt]','HWA [m/s]','HWA [m3/s]'
  160 format (' ',6x,a6,2x,a6,3x,a9,1x,a10,3x,a10,1x,a9,1x,a10)
```

```
  162 format (' ',6x,a6,2x,a6,2x,a10,1x,a9,1x,a10)
      if (vtype .eq. 'LDA ') write (1,170)
      if (vtype .eq. 'HWA ') write (1,172)
      if (vtype .eq. 'BOTH') write (1,174)
  170 format (6x,' ------',2x,'------',3x,'---------',1x,'----------')
  172 format (6x,' ------',2x,'------',2x,'----------',1x,'---------',
     +                                               1x,'----------')
  174 format (6x,' ------',2x,'------',3x,'---------',1x,'----------',
     +                3x,'----------',1x,'---------',1x,'----------')
c
      xtot=0.0
      ytot=0.0
      qldatot=0.0
      qhwatot=0.0
      do 30  i=1,nx
         do 40  j=1,ny
            if (i .eq. 1) xsize(i,j)=x(i+1,j)-x(i,j)
            if (i .eq. nx) xsize(i,j)=x(i,j)-x(i-1,j)
            if ((i .gt. 1) .and. (i .lt. nx))
     +                           xsize(i,j)=(x(i+1,j)-x(i-1,j))/2.
            if (j .eq. 1) ysize(i,j)=y(i,j+1)-y(i,j)
            if (j .eq. ny) ysize(i,j)=y(i,j)-y(i,j-1)
            if ((j .gt. 1) .and. (j .lt. ny))
     +                           ysize(i,j)=(y(i,j+1)-y(i,j-1))/2.
c
c     ********************** HWA CALIBRATION EQUATION ************************
c
            if (vtype .ne. 'LDA ')
     +      vhwa(i,j)=(volt(i,j)**2/4.136-1.252)**2.5
c           This equation is only an example of a HWA calibration equation.
c
            qlda(i,j)=vlda(i,j)*xsize(i,j)*ysize(i,j)*1e-4
            qhwa(i,j)=vhwa(i,j)*xsize(i,j)*ysize(i,j)*1e-4
            if (vtype.eq.'LDA ') write(1,180) x(i,j),y(i,j),
     +                                          vlda(i,j),qlda(i,j)
            if (vtype.eq.'HWA ') write(1,182) x(i,j),y(i,j),volt(i,j),
     +                                          vhwa(i,j),qhwa(i,j)
            if (vtype.eq.'BOTH') write(1,180) x(i,j),y(i,j),
     +                 vlda(i,j),qlda(i,j),volt(i,j),vhwa(i,j),qhwa(i,j)
  180       format(' ',5x,f7.2,1x,f7.2,5x,f5.2,5x,g8.2,
     +                                  6x,g9.3,1x,f5.2,5x,g8.2)
  182       format(' ',5x,f7.2,1x,f7.2,5x,g9.3,1x,f5.2,5x,g8.2)
            if (j .eq. 1)  xtot=xtot+ysize(i,j)
            if (i .eq. 1)  ytot=ytot+ysize(i,j)
            qldatot=qldatot+qlda(i,j)
            qhwatot=qhwatot+qhwa(i,j)
   40       continue
   30    continue
      vldaavg=qldatot/(xtot*ytot*1e-4)
      vhwaavg=qhwatot/(xtot*ytot*1e-4)
      write (1,' (a1) ')  ' '
      if (vtype .eq. 'LDA ') write (1,190) 'LDA -  ',vldaavg,qldatot
      if (vtype .eq. 'HWA ') write (1,190) 'HWA -  ',vhwaavg,qhwatot
      if (vtype .eq. 'BOTH') write (1,190) 'LDA -  ',vldaavg,qldatot,
     +                                     'HWA -  ',vhwaavg,qhwatot
  190 format (' '/9x,a7,'Average velocity =',f5.2,'  m/s'/16x,'Total flo
     +w rate  =',f6.3,' m3/s')
      close (unit=1)
      stop
      end
```

APPENDIX E
MANUFACTURERS' DATA

Fiber Optic LDV Components

LDV system accessories that simplify fluid flow measurements



88-53

TSI

New LDV technology. It creates new opportunities and provides new ways to look at fluid flow problems.

Consider the new fiber optic LDV systems from TSI. By adding fiber optics to traditional laser Doppler velocimetry systems, TSI Incorporated is providing solutions to a variety of difficult flow measurement problems--problems commonly encountered by scientists, researchers, and designers working in the area of fluid dynamics.

Two Ways to Measure Fluid Flows

TSI offers two ways to use fiber optics in LDV system configurations. One features focusing and receiving optics in a compact probe. The other provides a fiber optic link for standard TSI optics, separating them from other system components. Both options afford the user remarkable flexibility and reduce the potential for damage to the laser from hostile measurement environments.

Probes. Invasive as well as noninvasive measurements are possible with TSI fiber optic probes. Thanks to their compact design, small probes can be placed directly in the flow without creating an appreciable disturbance, or they can be built into models to eliminate nearly all disturbances to the flow. Because the probes are highly maneuverable, the measuring volume can be repositioned simply by moving the probe, rather than by moving the complete LDV system.

Links. For applications not requiring the compactness of the fiber probes, TSI offers transmitting and receiving fiber optic links for use with standard LDV systems. A *transmitting* fiber link can be placed between the laser and the measurement optics, or between any two transmitting optical elements. A *receiving* fiber link can be placed between the receiving optics module and the photodetector. These fiber links provide significant flexibility when positioning the system components relative to the measurement point.

New LDV Measurement Opportunities

TSI fiber optic LDV systems open up new measurement possibilities. They can be used for flow measurements in small or restricted spaces. Even areas with unusual or complex geometric configurations, or areas once considered inaccessible, can be reached using fiber optic components.

Fiber optic LDV systems are highly maneuverable. Probes can be positioned inside or outside the flow and maneuvered easily using a simple traversing arrangement. Fiber links separate the optics from the rest of the LDV system, minimizing the amount of hardware to be traversed and, thus, the size of the traverse table required. Additionally, the laser and the system electronics can be protected from harsh environments that may be associated with the flow.

TSI fiber optic LDVs also offer an efficient design. They use special couplers for directing the laser beam into and out of the optical fiber. To maintain the quality of the laser beam during transmission, all transmitting fibers are single-mode, polarization-preserving fibers. Two fibers are used to transmit each color. This unique design enables the energy density at the measurement volume to be higher than with a single-fiber system. Multimode fibers are used to receive the scattered light because they provide maximum efficiency. Both fiber types are immune to electrical noise.

The fiber optic LDV systems from TSI are designed to solve a variety of flow measurement problems. Several standard systems are available for use in research as well as industrial applications. Systems can also be tailored to meet unique requirements.

TSI Fiber Optic Probes

TSI offers a complete series of fiber optic probes. They are available in a variety of sizes, focal lengths, and wavelengths, and most probes are also available in one- or two-component versions.

Standard probes. TSI's standard probes can be used with most laser systems. Even systems with a frequency shifting capability are easily accommodated because each laser beam is transmitted individually through a single fiber. This is beneficial for applications involving flow reversals or low velocities, or those where high turbulence may be encountered.

The small probes (14 mm and 25 mm diameters) create very little disturbance in the flow. Because they are watertight, they can even be immersed in liquids. They can also be placed inside test models to eliminate flow disturbances.

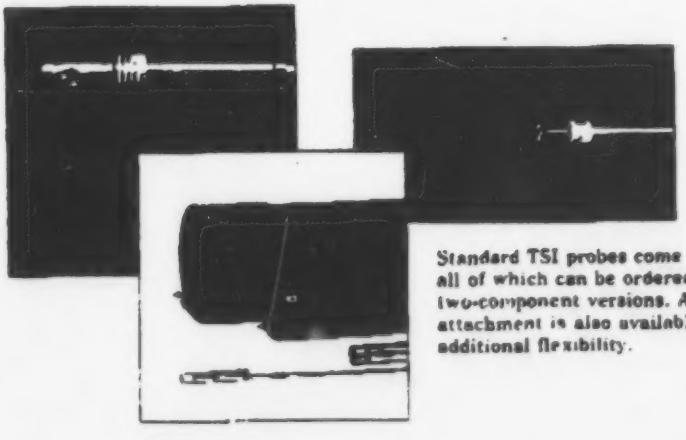
The large probes (83 mm and 190 mm diameters) are available for making measurements at greater distances from the probe's end. Their larger focal lengths and lens apertures provide good spatial resolution and maintain signal quality. Standard large probes are dust tight and can be made watertight on special request.

Beamsplitter probe. TSI also offers a unique beamsplitter probe. Available only in the 14mm diameter size, this probe is fitted with a single transmitting fiber for a single laser beam. A miniature beamsplitter, focusing lens, receiving lens, and a receiving fiber are all contained inside the probe. It is, therefore, a complete one-component optics system in itself, making it ideally suited for applications where the flow is unidirectional. Frequency shifting is not possible with the beamsplitter probe.

	Beamsplitter Probe	Small Diameter Probes				Large Diameter Probes			
System Number	9709	9710	9712	9720	9722*	9730	9732*	9740	9742*
Size: Outside Dia. (mm)	14	14	14	25	25	83	83	190	190
Length (mm)	125	100	100	156	156	300	300	680	680
Velocity Components	One	One	Two	One	Two	One	Two	One	Two
Lens Aperture (mm)	10	10	10	20	20	80	80	150	150
Working Dist. (mm): Air	60	60	60	102.135°	102.135°	120,250, 350**	120,250, 350**	450,750, 1200**	450,750, 1200**
Water	80	80	80	135,180°	135,180°	350†	350†	800†	800†

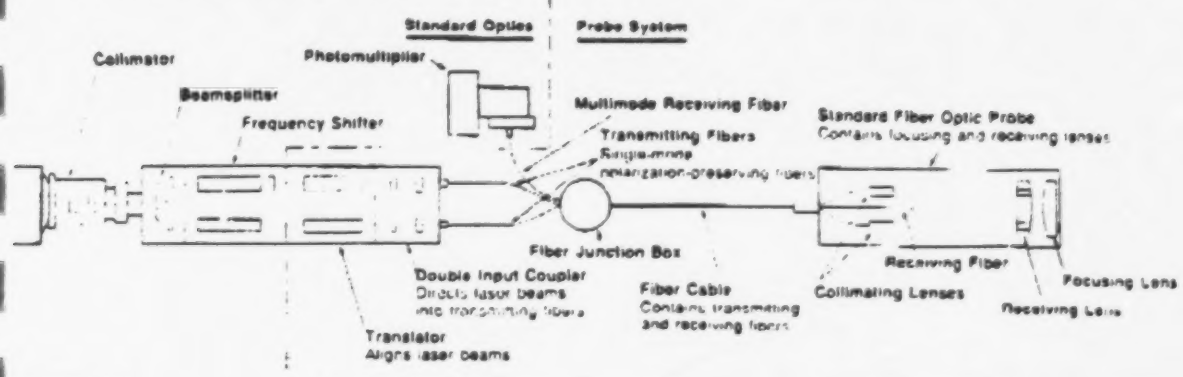
*These probes can be ordered with one of two available angles.
**These probes can be ordered with one of three lengths available for use in air.
†Available on special request.

Note: All dimensions are nominal.

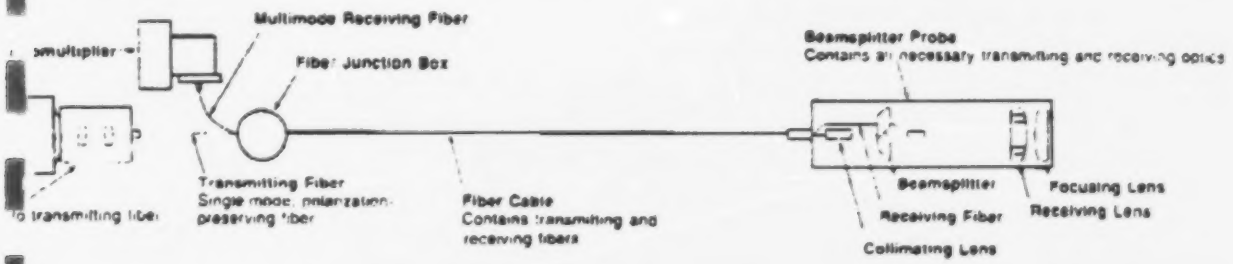


Standard TSI probes come in four sizes, all of which can be ordered in one- and two-component versions. A side-looking attachment is also available to provide additional flexibility.

System With Standard Fiber Optic Probe*

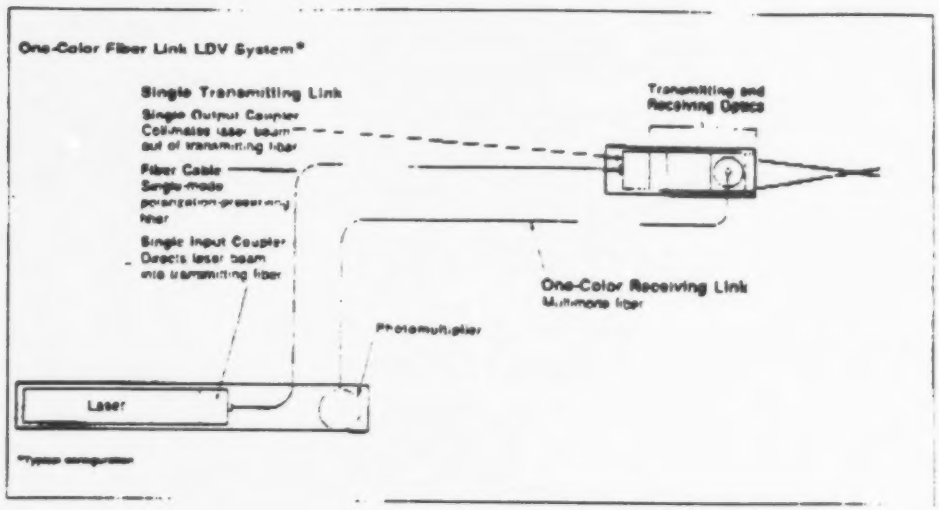


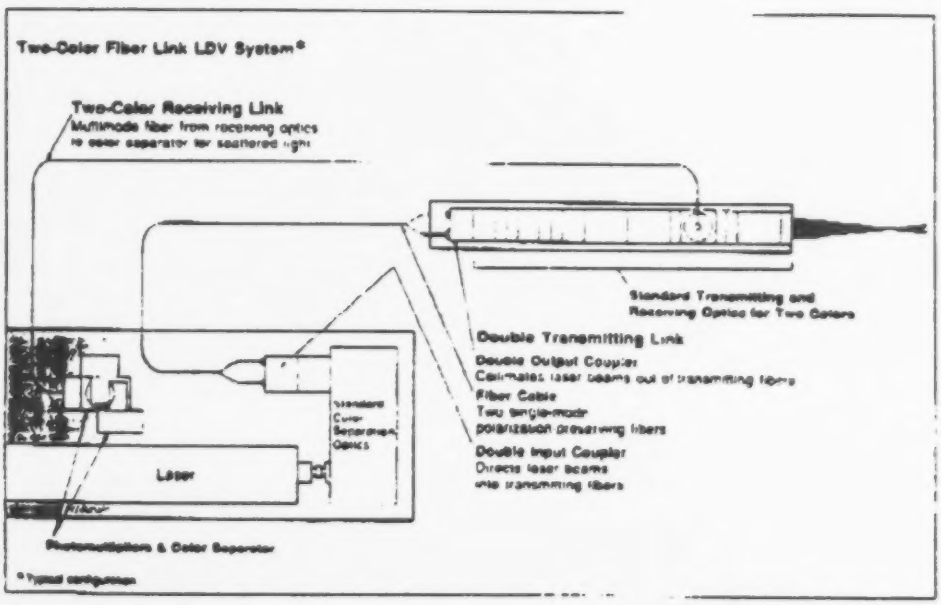
V System With Beamsplitter Probe*



TSI Fiber Optic Links

TSI fiber optic links use the same fiber and coupling technology as the probes. However, the fiber links are used with standard LDV optical components and are available for transmitting and receiving light in helium-neon and argon wavelengths.




Two-Color Fiber Link LDV System*
Two-Color Receiving Link
Multimode fiber from receiving optics to color separator for scattered light
Standard Transmitting and Receiving Optics for Two Colors
Double Transmitting Link
Double Output Coupler
Collimates laser beams out of transmitting fibers
Fiber Cable
Two single-mode polarization preserving fibers
Double Input Coupler
Directs laser beams into transmitting fibers
Standard Color Separation Optics
Laser
Photomultipliers & Color Separator
*Typical configuration

The fiber link enables a user to separate the laser from the rest of the system, protecting the laser and providing additional flexibility during operation. It also allows the laser to remain stationary, so that a smaller traverse table can be used—one that is small enough for the optics alone.

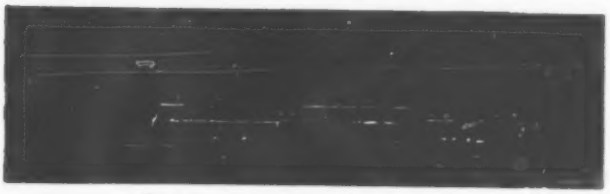
Typically, TSI fiber optic links include two types of fibers. *Transmitting* fibers can be used between the laser and the measurement optics, or between any two transmitting optical elements. *Receiving* fibers are placed between the receiving optics module and the photodetector.

Fiber links can be used with either a one-color laser system (helium-neon or single-color argon laser) or a two-color argon laser system. In two-color systems, a link can be placed between the color separator and the beamsplitter, and separate transmitting fibers are used for each color to provide maximum coupling power and transmission efficiency. Only one multimode receiving fiber is used in all fiber link systems; colors in the scattered light are separated using standard optics.

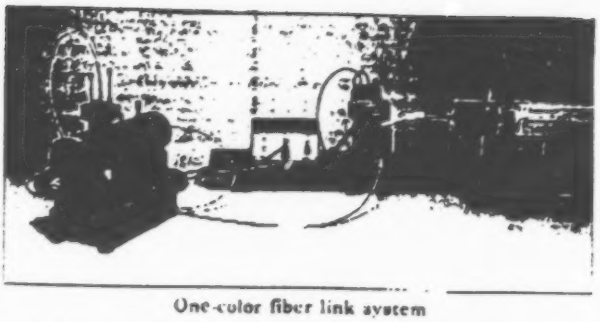
Solving Measurement Problems with New Technology

Fiber optics technology provides a degree of flexibility not available with conventional LDV systems. That's why TSI fiber optic LDVs are used for measurements with special requirements. Specific applications include:

- Open channel flows
- Hard-to-reach or hazardous flows
- Flows around complex geometric configurations such as rod bundles and turbo-machinery passages
- Flow fields in heat exchanger passages
- Exhaust gas flow in large heat recovery systems
- Tow tank experiments
- Flows around models in wind tunnel tests
- Sediment transport studies
- Combustion and flame studies
- Two-phase flows



Two-component fiber probe system



One-color fiber link system

TSI fiber optic LDV systems are solving a variety of flow measurement problems. Even if you have a unique or hard-to-measure flow application, TSI's specialized design and engineering services can help. Contact any of the sales offices listed below for more information about these services or any of the probes and fiber link systems discussed in this brochure.

Fiber optic probes and links are to be used with Class IIIb and Class IV certified laser systems.

TSI

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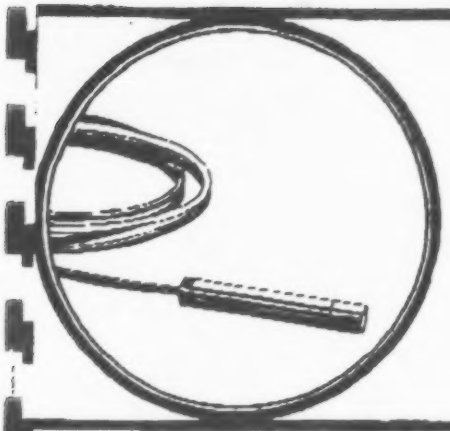


Fiber Optic LDV Probe Systems

14 and 25 mm Series

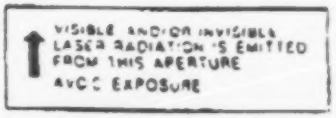
Specifications

	Model 9700	Model 9710	Model 9712	Model 9720		Model 9722	
Type	14 mm	14 mm	14 mm	25 mm		25 mm	
Velocity Components Measured	One*	One	Two*	One		Two*	
Physical Characteristics							
Probe O.D.	14.22 mm ±0.13 mm	14.22 mm ±0.13 mm	14.22 mm ±0.13 mm	25.15 mm ±0.13 mm		25.15 mm ±0.13 mm	
Probe Length (nominal)	125 mm	100 mm	100 mm	155 mm		155 mm	
Working Distance (nominal)							
Air	60 mm	60 mm	60 mm	102 mm	135 mm	102 mm	135 mm
Water	80 mm	80 mm	80 mm	135 mm	180 mm	135 mm	180 mm
Cable Size (nominal)	7.5 mmϕ	7.5 mmϕ	7.5 mmϕ	7.5 mmϕ	7.5 mmϕ	7.5 mmϕ	7.5 mmϕ
Optical Characteristics							
Probe Head Beam Spacing (nominal)	8 mm	8 mm	8 mm	15 mm	15 mm	15 mm	15 mm
Measuring Volume (in air)**							
Diameter	0.14 mm	0.14 mm	0.14 mm	0.11 mm	0.14 mm	0.11 mm	0.14 mm
Length	2.4 mm	2.4 mm	2.4 mm	1.6 mm	2.7 mm	1.6 mm	2.7 mm
Number of Fringes (514.5 nm)	30	30	30	25	25	25	25
Frequency Shift Possible	No	Yes	Yes	Yes	Yes	Yes	Yes
Fibers							
Transmitting Fiber	Polarization preserving, single-mode type.						
Receiving Fiber	Multimode, graded-index type.						
Cable Length	10 m.						
Power Throughput Efficiency***							
632.8 nm Probes	45% typical with 10 mW input power.						
514.5 to 488 nm Probes	30% typical with 10 mW input power.						
Receiving Channel Efficiency	40% minimum (measuring volume to detector)						
Exterior Materials							
Probe Housing	Stainless steel, nickel plated brass, black anodized aluminum, Buna N o-ring.						
Lens Coating	Multilayer dielectric, anti-reflective.						
Cable Jacket	PVC.						
Environmental							
Temperature Range	0°C to 60°C for operation, storage, and shipping.						
Pressure, immersibility	Sealed for water immersion to 1.5×10^5 Pa (1.5 atm) gauge pressure (15 m depth).						

*Two component probe models use the 514.5 nm and 488 nm argon-ion laser wavelengths only; the Model 9700 uses only the 632.8 nm wavelength.
**At $1/e^2$ intensity.
***Power throughput efficiency is defined as the ratio of the power at the measuring volume to the power into the coupler, with the laser operating in the TEM_{00} mode.

Specifications are subject to change without notice.

Fiber optic probes are to be used with Class IIIb and Class IV certified laser systems.



All probes have this label.

Table Of Fringe Spacings

Internal Beam Spacing (mm)	Working Distance (mm)	Wavelength (nm)	Fringe Spacing (μm)
8	60	632.8	5.39
		514.5	4.38
		488.0	4.15
15	102	632.8	4.65
		514.5	3.78
		488.0	3.58
15	135	632.8	6.07
		514.5	4.94
		488.0	4.68

Actual fringe spacing may vary from table value for manufactured probes by up to ±3.0% for 14 mm probes, ±1.7% for 25 mm probes. Each probe is inscribed with wavelength and with its fringe spacing accurate to 0.5%.

Ordering Information

To determine the model number for a TSI fiber optic probe, select the wavelength and working distance from the Model Number Table. The appropriate model number can be found in the lefthand column. The modules which make up each probe model are listed in the Configuration Table.

Configuration Table

Component Number	Component Description	Probe Model Number				
		9700-2	9710-X	9712-1	9720-X-Y	9722-1-Y
9259	Double translator		1	2	1	2
9260	Input coupler	1				
9262	Double input coupler		1	2	1	2
9269	Receiving fiber collimator			1		1
9270-2	Probe (14 mm, no shift)	1				
9272-X	Probe (14 mm)		1			
9273	Probe (14 mm, 2 comp)			1		
9278-G	Probe (25 mm)				1	
9279-PV	Probe (25 mm, 2 comp)					1
10953	Light tube			1		1
10954	Photodetector base	1	1		1	

Note - Dash numbers for the probes correspond to the dash numbers for the probe systems listed in the Model Number Table. Here X corresponds to wavelength (i.e. -11 for Ar 488 nm, -12 for Ar 514.5 nm, -2 for HeNe 632.8 nm, and -1 for both Ar wavelengths) and Y corresponds to working distance in air (-10 for 102 mm and -13 for 135 mm). When ordering a probe separately, the dash number must be specified (for example 9278-2-13).

Model Number Table

Model Number	Nominal Dia. (mm)	Wavelength (nm)	Working Distance (mm) Air	Water
9700-2	14	HeNe 632.8	60	80
9710-11	14	Ar 488	60	80
9710-12	14	Ar 514.5	60	80
9710-2	14	HeNe 632.8	60	80
9712-1	14	Ar 488 and 514.5	60	80
9720-11-10	25	Ar 488	102	135
9720-12-10	25	Ar 514.5	102	135
9720-2-10	25	HeNe 632.8	102	135
9720-11-13	25	Ar 488	135	180
9720-12-13	25	Ar 514.5	135	180
9720-2-13	25	HeNe 632.8	135	180
9722-1-10	25	Ar 488 and 514.5	102	135
9722-1-13	25	Ar 488 and 514.5	135	180

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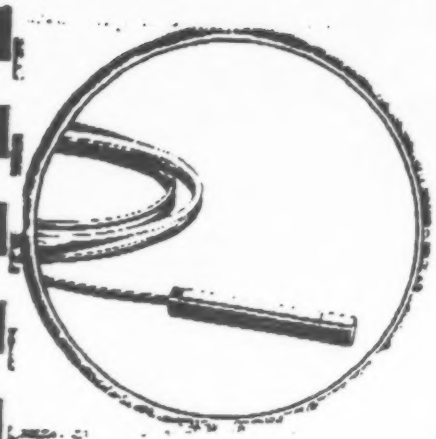


Laser Velocimetry Systems

Specifications

Fiber Optic LDV Probe Systems
83 and 190 mm Series

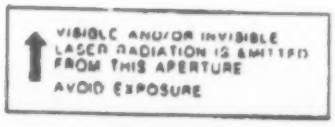
Specifications

	9730	9732	9760	9762
Type	83 mm	83 mm	190 mm	190 mm
Velocity Components Measured	One	Two*	One	Two*
Physical Characteristics				
Probe O.D.	83 mm	83 mm	190 mm	190 mm
Probe length (nominal - dust tight)	305 mm	305 mm	692 mm	692 mm
Working Distance (nominal)				
Air - with std. lenses - not incl.	120-500 mm	120-500 mm	450-1500 mm	450-1500 mm
Weight	3 Kg	3 Kg	20 Kg	20 Kg
Cable Size (nominal)	7.5 mm	7.5 mm	7.5 mm	7.5 mm
Optical Characteristics				
Probe Head Beam Spacing (nominal)	50 mm	50 mm	135 mm	135 mm
Number of Fringes (514.5 nm)	63	63	38	38
Clear Aperture	60 mm	60 mm	150 mm	150 mm
Beam Diameter**	1 mm	1 mm	4.5 mm	4.5 mm

Fibers	
Transmitting Fiber	Polarization preserving, single-mode type.
Receiving Fiber	Multimode, graded-index type.
Cable Length	10 m.
Power Throughput Efficiency* **	
632.8 nm Probes	45% typical with 10 mW input power.
514.5 to 488 nm Probes	30% typical with 10 mW input power.
Exterior Materials	
Probe Housing	Black, anodized aluminum, Buna N o-ring.
Lens Coating	Multilayer dielectric, anti-reflective.
Cable Jacket	PVC.
Environmental	
Temperature Range	0°C to 60°C for operation, storage, and shipping
Pressure, immersibility	Dust tight. Sealed for water immersion to 1.5×10^5 Pa (1.5 atm) gauge pressure (15 m depth) by special order.

*Two component probe models use the 514.5 nm and 488 nm argon-ion laser wavelengths only.
**At 1/e² intensity
***Power throughput efficiency is defined as the ratio of the power at the measuring volume to the power into the coupler, with the laser operating in the TEM_{00} mode.

Specifications are subject to change without notice.



Fiber optic probes are to be used with Class IIIb and Class IV certified laser systems.

All probes have this label. 88-53

Measurement Volume Specifications

The 83 mm and 190 mm series probes use standard TSI lenses (ordered separately) which are field replaceable.

These specifications give measurement volume dimension for typical lenses using 514.5 nm wavelength.

Probe	Lens Model #	F.D. (mm)	Fringe Spacing (micron)	Measuring Volume Length (mm)	Measuring Volume Diameter (mm)
[illegible]	9167-120	120	1.41	0.49	0.09
[illegible]	9167-250	250	2.70	1.79	0.17
[illegible]	9167-350	350	3.74	3.46	0.24
[illegible]	9167-500	500	5.27	6.88	0.34

Probe	Lens Model #	F.D. (mm)	Fringe Spacing (micron)	Measuring Volume Length (mm)	Measuring Volume Diameter (mm)
[illegible]	9169-450	450	1.85	0.50	0.07
[illegible]	9169-750	750	2.90	1.24	0.11
[illegible]	9169-1140	1140	4.26	2.70	0.16
[illegible]	9169-1500	1500	5.80	4.99	0.22

Ordering Information

To select the correct Fiber Optic Probe System for your application:

1. Select front lens with appropriate focal distance using measurement volume spec table.
2. Match probe type 973X or 976X for this lens.
3. Select number of components to be measured (9730 or 60 for 1D, 9732 or 62 for 2D).
4. If one component probe, select laser wavelength suffix 2 for 632.8, 11 for 488 nm, 12 for 514.5.

Example:

If 250 mm F.D. in air required with HeNe Laser, one component, order:

Lens - 9167-250
Probe - 9730-2

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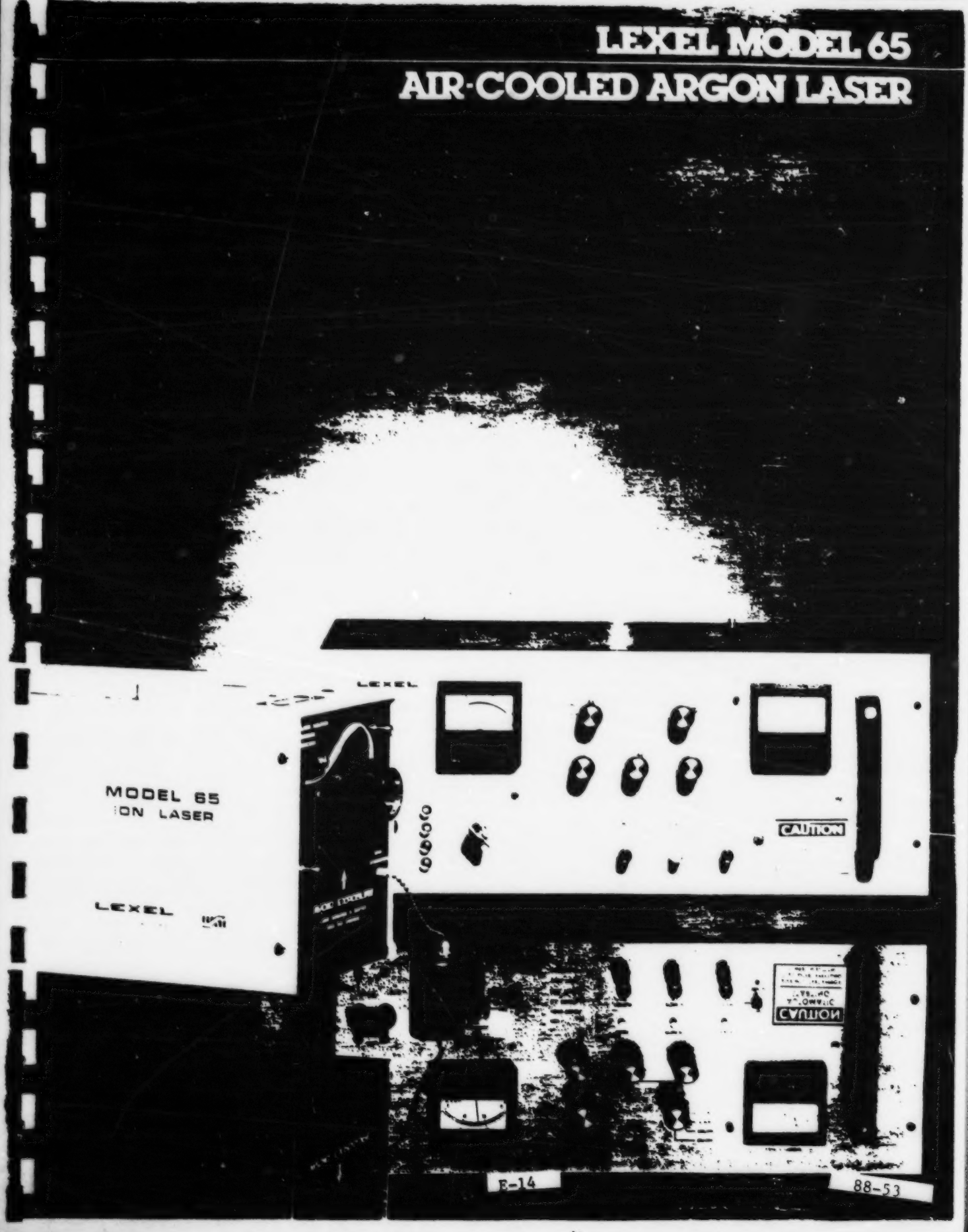
LEXEL MODEL 65
AIR-COOLED ARGON LASER



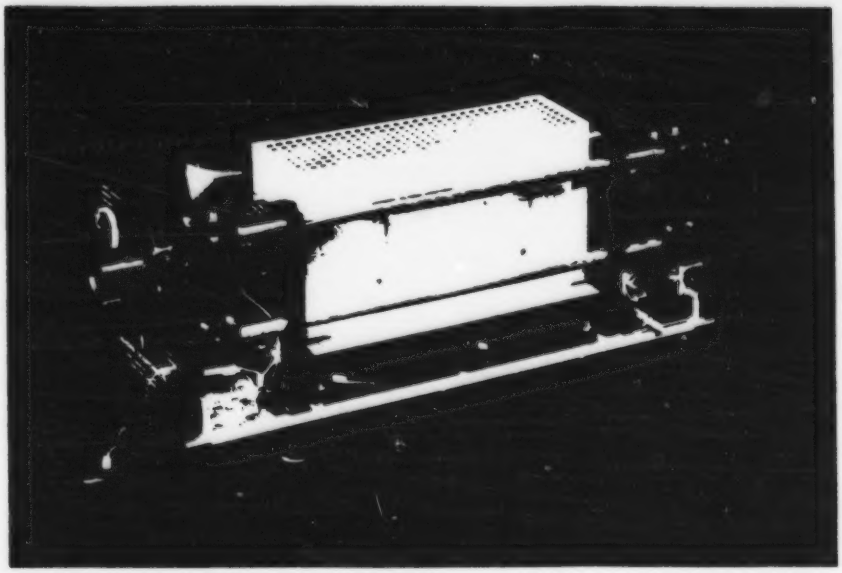
LEXEL MODEL 65

The name LEXEL has come to mean excellence in ion lasers. The Model 65 now extends this excellence to air-cooled technology.

In achieving this major advance in air-cooled technology, LEXEL engineers have blended the best of our existing designs with insightful innovations appropriate to the air-cooled environment. The result is outstanding performance, reliability and stability.

Whether the Model 65 is in a stringent, demanding one-of-a-kind application or in stand-alone OEM systems that mandate long, service-free periods, it is the only air-cooled ion laser to master such demands.

This exceptional operating performance is made possible by the advanced design elements and new technology of the Model 65. They include the ceramic-and-metal plasma tube, cooling air velocity matched to plasma tube temperature gradients (patent pending), vibration-and-temperature-isolated solid Invar resonator (patent pending), unique sealed rigid metal intracavity space (patent pending), and the conservatively designed power supply.



Laser Head The LEXEL Model 65 laser head contains the plasma tube, resonator structure, laser optics, and air-cooling system in the most advanced design available. The LEXEL laser head components and features described here are the result of an extensive engineering effort which has yielded unmatched stability, reliability and ease of operation.

Plasma Tube The Model 65 plasma tube incorporates LEXEL's proven design philosophy which has led to the industry standard in reliability and performance. Incorporated in the design are:

—Rugged ceramic and metal construction in which electrodes and feedthrough leads are brazed and welded assemblies. This design eliminates glass envelopes and their associated fragile pin seals.

—High-conductance internal gas return path which provides for optimum pressure equalization and dependable starting. This design feature overcomes breakage problems associated with glass external gas return paths.

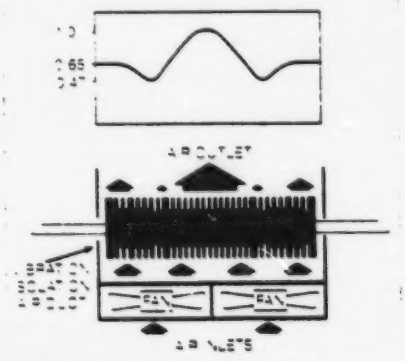
—Large-capacity free-flow gas supply which provides sufficient gas for upwards of 6000 hours of operation.

—State-of-the-art vacuum tube processing techniques are employed in the production of Model 65 plasma tubes. One of LEXEL's major contributions to ion laser reliability is the completely vacuum-compatible plasma tube. The entire tube is processed at high temperature and high vacuum. For example, the Brewster-angle windows are sealed in a proprietary manner using a fused quartz-to-quartz seal which is bakeable to more than 1000°C. Moreover, at the completion of processing, the contamination-free copper pinch-off method unique to LEXEL seals and separates the tube from the vacuum processing station.

—Additionally, the ceramic-and-metal plasma tube design lends itself to high-volume production techniques in common use today by vacuum tube manufacturers.

Unique Air-Cooling System Laser stability and performance are influenced greatly by the plasma tube cooling system. Specifically, the plasma tube must be cooled efficiently to remain thermally stable during normal operation. Additionally, the heat must be removed from the plasma tube without introducing thermal gradients to the resonator or optics which can cause mechanical detuning and instability. LEXEL engineers have advanced the state of the art in air-cooled ion lasers with the introduction of the new and unique Vel Grad™ cooling system.

The Vel Grad™ cooling system matches the air-flow velocity to the temperature gradient of the plasma tube. This matching of flow velocity to temperature profile serves to greatly increase the cooling efficiency of the plasma tube.



Because of the high efficiency cooling system, the thermal stability of the LEXEL Model 65 is unmatched, leading to superior power stability and beam-pointing stability.

The Vel Grad ™ system's matching of airflow velocity to temperature gradients is accomplished through a carefully engineered forced-air design employing two optimally positioned fans inside an isolated flow channel (patent pending). This straight-through flow channel eliminates using the laser head enclosure as a portion of the cooling duct.

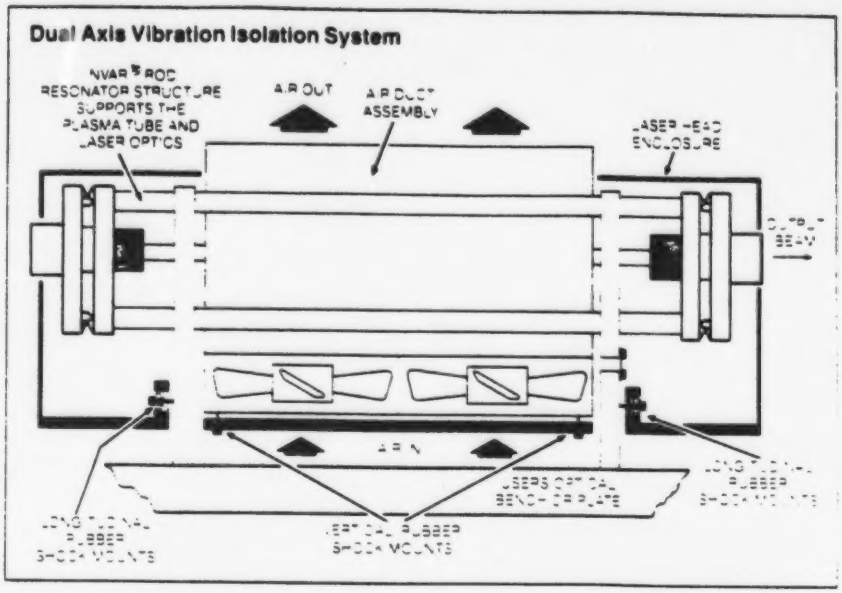
Unlike air-cooled lasers which use fans to draw air into the laser head and across the plasma tube as well as across the resonator and optics, the Vel Grad ™ system forces the cool air across the plasma tube only. The flow duct acts as a nozzle directing the cool air to the plasma tube and keeps heated air from the resonator structure and laser optics. The Model 65 fans operate at ambient temperature, not at exhaust-duct elevated temperature, thus extending fan operating life.

For special applications, the Model 65 can be provided with a water cooling jacket. This may be required in applications where water cooling is not objectionable and where an elevated temperature in the operating environment cannot be tolerated.

Resonator Structure The optical resonator is the most important structure affecting the overall performance of the laser. The Model 65 resonator incorporates time-tested features found in all LEXEL water-cooled ion lasers. These include the solid-rod Invar construction which provides unmatched mechanical rigidity and superior thermal stability, along with LEXEL's patented kinematic mirror suspension system. The mirror suspension system, utilizing three re-entrant springs, has time and again demonstrated its ability to withstand shock and vibration that would misalign other laser designs.

Additionally, LEXEL engineers have designed a new and unique resonator mounting system for the Model 65 air-cooled ion laser.

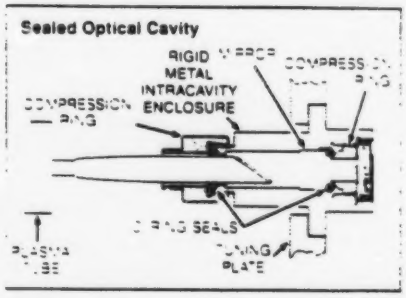
LEXEL's dual-axis vibration isolation system removes the effect of fan vibrations on the optical resonator (patent pending).


Dual Axis Vibration Isolation System
INVAR ® ROD RESONATOR STRUCTURE SUPPORTS THE PLASMA TUBE AND LASER OPTICS
AIR OUT
AIR DUCT ASSEMBLY
LASER HEAD ENCLOSURE
OUTPUT BEAM
AIR IN
USER'S OPTICAL BENCH OR PLATE
LONGITUDINAL RUBBER SHOCK MOUNTS
LONGITUDINAL RUBBER SHOCK MOUNTS
VERTICAL RUBBER SHOCK MOUNTS

This eliminates the vibration-caused problems of optical noise and beam wander found in other air-cooled lasers.

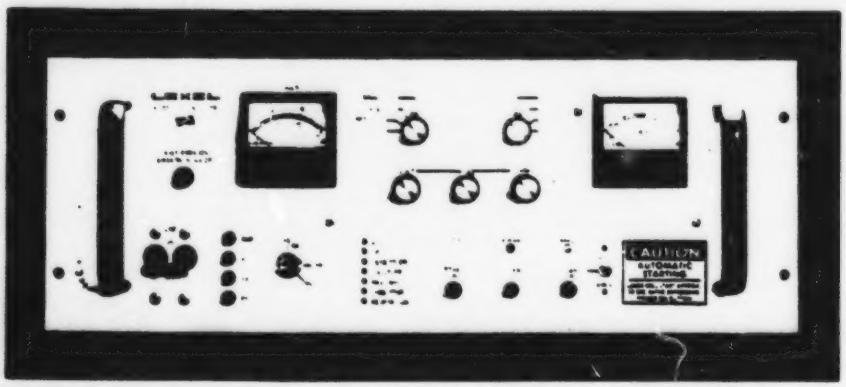
Another design feature unique to the Model 65 is that the resonator itself can be mounted to the bench. Since the cooling fans, airflow duct and laser head enclosure are suspended via shock mountings from the resonator structure (patent pending), negligible vibrations can reach the user's optical train.

Laser Optics The most troublesome and common cause of mode degradation and power drop-off is contamination of the optical surfaces of the cavity. LEXEL lasers have long been the only lasers available with totally sealed optical cavities. In the Model 65's new and unique sealing technique, the optical seal consists of only one rigid metal part sealed to the mirror and Brewster extension by O-rings. These rigid metal enclosures not only seal the optics from contamination but support the glass Brewster extensions at the ends away from the plasma tube, thus giving mechanical stability to these glass parts (patent pending). These metal parts are cleaned prior to installation using a proprietary procedure—and left sealed. The mirrors and Brewster windows will rarely have to be cleaned.



Power Supply The power supply provides all the excitation energy and electronic circuitry necessary to operate, monitor and control the laser. The laser power control circuitry is the same as that which has been used in our reliable water-cooled lasers. The power supply also contains status indicators which graphically show the operating condition of the various interlocks and safety devices found in the Model 65 head and power supply.

The Model 65 can be ordered to operate from 100 / 115 / 200 / 208 / 220 / 230 / 240 VAC, 50/60 Hz, single-phase, 20-amp service or 220 / 230 / 240 VAC, 50/60 Hz, single-phase, 30-amp service. The Model 65, like other LEXEL ion lasers, incorporates controls for accurate setting of cathode temperature, which provides long plasma tube life.



Standard Features of the Model 65

—Current Control operation allows the user to set the operating current level of the laser. The current regulator will maintain a precise current through the plasma tube and therefore a constant power output regardless of variations in input line voltage.

—Tilt-out current regulator assembly provides easy access to any of the components located on this assembly.

—Laser operating parameter meter permits monitoring any one of the following:

- Laser Tube Current
- Laser Tube Voltage
- Regulator Voltage
- AC Control Voltage

—A multi-tapped auto transformer is employed for efficient matching of various line voltages to the Model 65 power supply. The regulator circuit will thereafter compensate for normal line voltage variations.

The Model 65 contains many safety features:

—Interlocked protective covers minimize the potential of electric shock on both the laser head and power supply.

—The plasma tube is protected from overheating (in the event of fan failure or cooling duct blockage) by a thermistor mounted on the cooling fin assembly.

—The air-cooled transistor regulator heatsink in the Model 65 power supply is also protected against overheating by a snap-action thermostat located on that assembly.

—There are also 4 levels of over-current protection for the plasma tube and power supply components. The first level is a current limit circuit which prevents the laser current from exceeding a fixed safe limit. If this were exceeded for some reason, the second level of protection, a current trip circuit, will de-energize the laser. The third level of protection will operate when a severe overload causes the rectifier fuses to open and thus remove AC voltage from the diode rectifiers. The fourth level is a line circuit breaker which will remove all AC voltage from the power supply in case of a major short circuit.

—Individual interlock status indicators. This chain consists of the following interlocks, each having its own indicator: Remote Connectors, Tube Temperature, Regulator Temperature, Power Supply Cover, Head Cover, Key, and Fuse F2. Only when all the interlocks are closed will the master INTLK indicator come on and permit the laser to be energized.

—A fan off delay circuit permits the cooling fans to run for 2 minutes after de-energizing the laser.

Options Available for the Model 65

7507—Panel Mounted Power Meter. The 7507 Panel Mounted Power Meter allows the output power of the laser to be read directly on one of four different power ranges. These 4 ranges (300 mW, 100 mW, 30 mW, and 10 mW) also switch the gain of the light regulator circuit, thereby providing excellent resolution in setting the light output. This option also provides a BNC connector at the rear of the power supply which permits remote monitoring of the laser power output. It also provides a signal at the recorder output jack which may be used to operate a power indicator in another location, such as the Model 508 Remote Power Monitor. (Requires 7516.)

7516—Light Regulator. A beamsplitter and a silicon photocell sample a small portion of the output beam. The output of the photocell is amplified and compared to a reference signal in a different circuit that automatically adjusts the laser current to maintain a constant power output. The light regulation option also allows the light level to be adjusted or modulated externally. D.C. voltages applied to the EXT MOD connection will provide the following: A +7 volt signal will drive the power output from maximum to a minimum level; or a −7 volt signal will drive the power output from a minimum level to maximum power.

7517—Automatic Starting. This circuit automatically starts the plasma tube about 20 seconds after the power supply is turned on. The manual LASER START switch is still operative and the automatic feature can be easily switched off at any time.

7518—Remote Turn On, Off, Start. A connector at the rear of the power supply can be appropriately wired to the user's system for remotely turning on the power to the plasma tube, starting the laser, providing accessibility to the interlock chain, and turning the laser off.

Accessories

504—Laser Power Meter

506—Polarization Rotator

508—Remote Power Monitor

511—Temperature-Compensated Prism Wavelength Selector. Ultra-stable single line operation is achieved with the Model 511 Prism Wavelength Selector using LEXEL's time-tested thermal counter-rotation design to compensate automatically for thermal changes in the index of refraction of the fused silica Brewster prism. The laser remains virtually peak tuning for ±10°C changes in ambient temperature.

512—Multiline Mirror Holder. This assembly holds the high reflector mirror to allow multiline operation.

513—Mounting Bars. These bars replace the feet normally installed on the laser and permit attaching the laser to a plate from above instead of through an optical table. Sufficient clearance for cooling air flow is automatically provided by these bars. Mounting holes are on 1-inch centers so that the laser can be bolted directly to an optical table.

514—Optical Thread Adapter. This adapter threads into the 1"-32 optical thread at the output aperture of the laser converting it to a 1"-32 female thread for mounting optical accessories with the smaller thread.

BRH Compliance The LEXEL Model 65 complies with all applicable laser safety standards as required by the Bureau of Radiological Health (BRH) Laser Products Performance Standards.

On the power supply panel, these consist of the KEY CONTROL and the allow operation of the laser only when the key is inserted and turned to the ON position, the LASER RADIATION EMISSION INDICATOR which comes on when the power supply is turned on and operates both before and during laser operation, and a REMOTE CONNECTOR is located on the rear panel which can be connected to interlocks outside of the laser system.

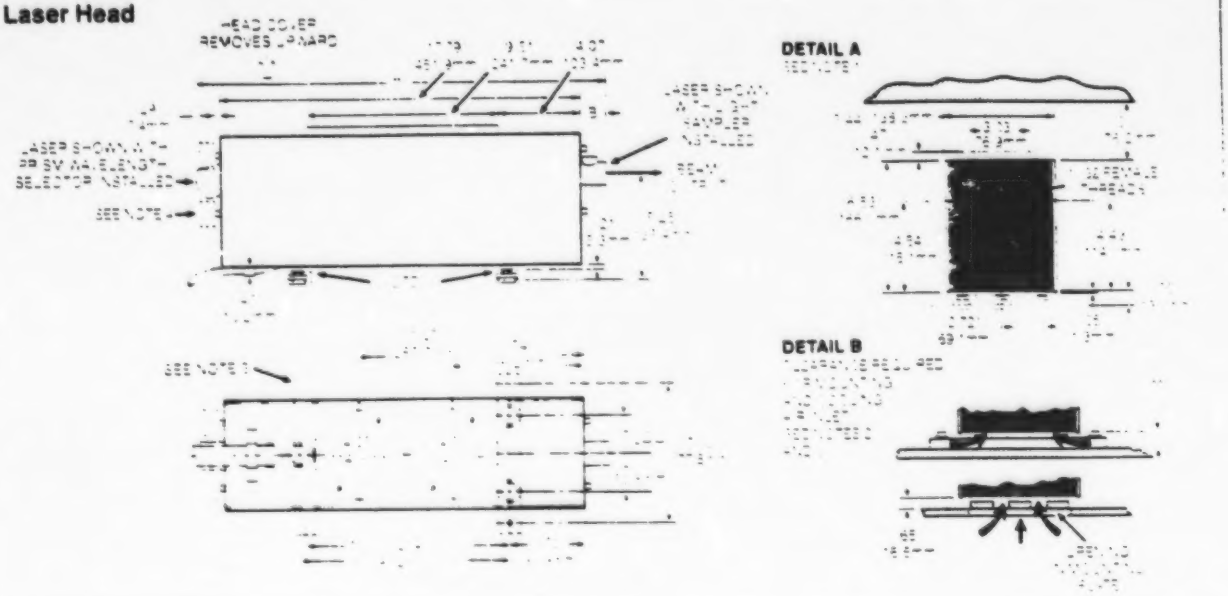
On the laser head, these consist of a LASER RADIATION EMISSION INDICATOR which provides a visual signal of emission and whenever the laser is operating, an INTERLOCK DEFEATED INDICATOR which lights up when the head cover is removed and the safety interlocks are defeated, and a BEAM ATTENUATOR which blocks the laser beam by means of a beam terminator and a WARNING LOGOTYPE as shown below.

Laser Reflectors

Wavelength (nm)	Type	CATALOG NUMBER Transmitter	High Reflector

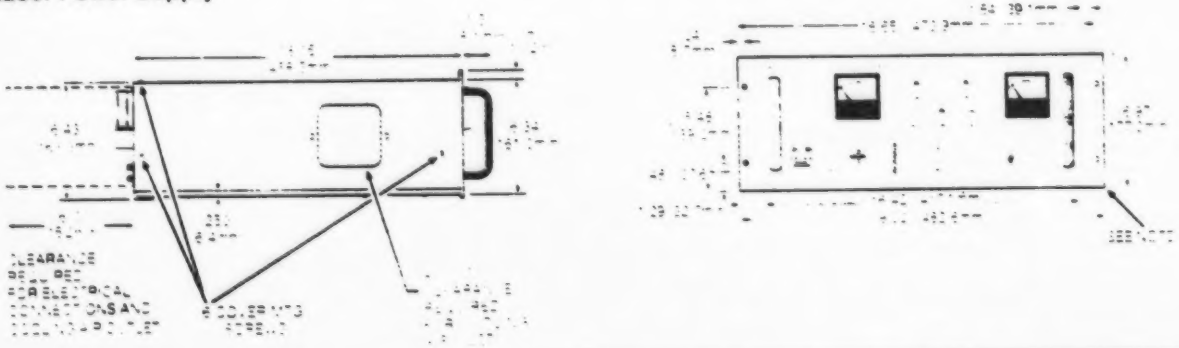
Dimensional Drawings

Laser Head



Configuration	Dimension A	Dimension B
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Laser Power Supply



Model 65 Specifications

Guaranteed Fundamental Mode Power (milliwatts)[2]							
Model	Multiline[3]	All Blue[4]	Single Line[5] 514.5 nm	496.5 nm	488.0 nm	476.5 nm	457.9 nm
65-07	75	40	25	5	35	5	1
65-05	50	25	15	3	25	3	—
65-02	25	15	10	1	15	1	—

Beam Diameter (at 1 e² points)[6]	488.0 nm TEM$_{00}$	0.8 mm
Beam Divergence (full angle)[6]	488.0 nm TEM$_{00}$	0.9 mrad
Beam Polarization Ratio	>100:1 E-vector vertical	
Cavity Mirror Configuration	Long radius transmitter/Extinction reflector (for TEM$_{00}$)	
Cavity Length[7]	Multiprism wavelength selector Multiline wavelength selector	44 cm 40 cm
Longitudinal Mode Spacing (c/2L)[7]	Multiprism wavelength selector Multiline wavelength selector	341 MHz 375 MHz
Optical Resonator	Stable hybrid structure	
Amplitude Power Stability Average variation in a 1 hour period tested over 12 hours after a 10 minute warmup	Light control[8] Current control	< ±0.4% < ±1.5%
Turn On Power	Light control	>95% of stabilized power measured immediately after turn on
Optical Noise (10 Hz to 2 MHz)	Typical light control[9] Maximum ripple current control Typical high frequency component	< 1.0% rms < 1.5% rms < 0.7% rms
Plasma Tube Bore Material	Beryllium Oxide (BeO) ceramic	
Laser Head Size (HxWxL)	7" x 5.5 x 20.1" (178 x 140 x 511 mm)	
Laser Head Weight	25 lbs (11 kg)	
Power Meter Ranges[10]	300 mW-100 mW-30 mW-10 mW	
Electrical Service Required	100 v AC single-phase 50/60 Hz 20 amp service 115 v AC single-phase 50/60 Hz 20 amp service 220 v AC single-phase 50/60 Hz 10 amp service	
Input Voltage Range[11]	90.0-110.0 V AC or 103.5-126.5 V AC or 198.0-242.0 V AC	
Maximum Line Current Input Power	100 v AC-17.5 amps 1750 W or 115 v AC-15 amps 1750 W or 220 v AC-8 amps 1750 W	
Power Supply Size (HxWxD)	7.0 x 19.0 x 19.0" (178 x 483 x 483 mm)	
Power Supply Weight	75 lbs (35 kg)	

[illegible]

[illegible]

Optical safety features [illegible]

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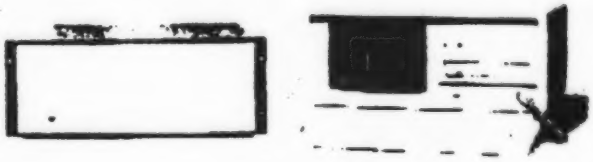
Laser Velocimetry Systems

Electronics

Model IFA 550
Intelligent Flow Analyzer For Laser Velocimetry

- No user interaction needed
- Automated operation
- Automatic data validation ensures only good measurements
- Large dynamic range
- Processing independent of signal amplitude
- Can be remotely operated using IBM PC
- Real-time data analysis on IBM PC
- Manual rescaling of analog output to optimize resolution



The IFA 550 Intelligent Flow Analyzer is a signal processor designed to extract velocity information from noisy signals derived from a laser Doppler velocimeter. The processor uses a new and unique approach for separating the signal from the noise. An automatic data validation capability results in a unique ability for the processor to give only good measurements. The processor can operate without any operator interaction in a "hands-off" mode, thereby making the measurement user independent.

The processor can be operated remotely using an IBM PC® computer which also gives a real-time display of the velocity variation at the measuring point. The processor, combined with the IBM PC, has the ability to seek and capture the signal to obtain velocity information. Thus, the processor, along with the LDV system, provides a fully-automated velocity measuring system. Such systems can be used for monitoring and diagnostic purposes without any operator interaction.

Specifications

Frequency Range	1 kHz to 15 MHz.
Time Resolution	2 ns.
High-pass Filters	1, 3 MHz; 1, 3, 10, 30, 100 kHz; and 100 Hz.
Low-pass Filters	1, 3, 10, 15 MHz and 1, 3, 10, 30, 100 kHz.
Filter Roll-off	30 dB per octave (100 dB per decade).
Input Voltage Range	0.1 mV to 1.0 V.
Input/Output	
Digital	Serial - RS-232-C standard. Parallel - 16-bit parallel (12-bit mantissa, 4-bit exponent).
Analog (optional)	0 to 10 volts (frequency full-scale selectable in powers of 2).
Input Power Requirements	100/110/220/240 V, 50/60 Hz.
Physical Dimensions	
Size (WHD)	48 x 17.8 x 41 cm (19 x 7 x 16 in.), standard rack.
Weight	7.25 kg (16 lb)
Display (on computer monitor, not included)	Real time velocity histogram.
Calculates	Mean velocity, turbulence intensity, standard deviation, data rate.
Controls	Filter settings.

Specifications subject to change without notice.

88-53

The IFA 550 is normally supplied complete with software written in Microsoft® Fortran and interface card and cables (TSI Model 6261) for the IBM PC and compatibles. Minimum system configurations are as follows:

- ☐ IBM XT, AT or compatible with 512K RAM
- ☐ 5¼" disk drive
- ☐ color graphics adapter
- ☐ composite or RGB monitor
- ☐ DOS 2.2 or higher

To Order, Specify:

A.	IFA 550	Includes interface and software
B.	IFA 550-00	IFA without interface or software, used as a base for analog system or as slave unit for multi-channel systems
B.	6262 (optional)	Analog interface board, outputs 0-10 volts DC signal proportional to Doppler frequency

Contact your nearest TSI office or representative for additional information.

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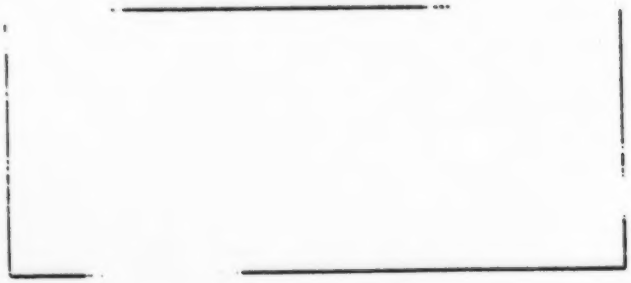

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88-53

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